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July 1985

Air Pollution and Acid Rain
Report No. 20

INTERACTIONS AMONG WATERFOWL, FISHES, INVERTEBRATES, AND MACROPHYTES IN FOUR MAINE LAKES OF DIFFERENT ACIDITY

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UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

EASTERN ENERGY AND LAND USE TEAM
Route 3, Box 44
Kearneysville, West Virginia 25430

Dear Colleague:

The Eastern Energy and Land Use Team (EELUT) is pleased to provide you with this report entitled "Interactions Among Waterfowl, Fishes, Invertebrates, and Macrophytes in Four Maine Lakes of Different Acidity". It is the twentieth report in our series dealing with air pollution and acid rain. Previous reports in this series are listed on the inside front cover.

In this research project two pairs of oligotrophic, headwater ponds that were physically similar but with markedly different acidities (pH 4.6 vs 6.3 and 4.8 vs 6.5) were studied to determine the influence of low pH waters on community structure and species interactions. Competitive interactions between waterfowl (black ducks) and fish were specifically examined.

We are interested in your comments concerning this publication and invite you to write or call us (phone 304/725-2061).

Sincerely,

R. Kent Schreiber

R. Kent Schreiber
Acting Team Leader, EELUT

Biological Report 80(40.20)
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Air Pollution and Acid Rain
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INTERACTIONS AMONG WATERFOWL, FISHES, INVERTEBRATES, AND MACROPHYTES IN FOUR MAINE LAKES OF DIFFERENT ACIDITY

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DISCLAIMER

Although the research described in this report has been funded in part by the U. S. Environmental Protection Agency through Interagency Agreement No. EPA-82-D-X0581 to the U.S. Fish and Wildlife Service, it has not been subjected to the Agency's required peer and policy review and does not necessarily reflect the views of the Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the Federal Government. This research has been funded as part of the National Acid Precipitation Assessment Program by the U.S. Fish and Wildlife Service.

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EXECUTIVE SUMMARY

This study focused on two pairs of ponds that were physically similar but which had markedly different acidities. Salmon Pond (pH 6.3) had fish, while 120 m away, Mud Pond (pH 4.6) was fishless. The second pair, Killman Pond (pH 6.5) and Unnamed Pond (pH 4.8), were also physically similar, but again the circumneutral pond had fish and the acidic pond was fishless. In Salmon and Mud ponds we studied macrophytes, zooplankton, macroinvertebrates, fish, and black ducks (Anas rubripes) and attempted to elucidate their interactions. We replicated the macrophyte, fish, waterfowl, and a portion of the macroinvertebrate work in Killman and Unnamed ponds.

Macrophyte abundance and species richness varied among the ponds. The acidic ponds had low species richness (Mud - 10; Unnamed - 6) and intermediate biomasses (33.8 and 74.6 g/m^2, respectively). Salmon Pond supported 15 species and 157.9 g/m^2 while Killman Pond had a similar species richness, 14, but very low biomass, 14.0 g/m^2. The differences in species richness were probably related to pH, and transparency differences probably explain the biomass pattern. It is unlikely that this distribution of macrophytes played a major role in shaping the ponds' fauna.

Eighteen species of zooplankton were identified from Mud Pond, and 21 species from Salmon Pond. Rotifer species richness and density were lower in Mud Pond (1.6 spp. per sample and 42.64 individuals per 10 l) than in Salmon Pond (5.25 spp. per sample and 503.51 individuals per 10 l). Crustacean species richness (4.4 spp. per sample) was similar for both ponds, but density was lower in Mud Pond than Salmon Pond (63.65 and 228.28

individuals per 10 l, respectively). Three large crustaceans, *Diaphanosoma brachyurum*, *Polyphemus pediculus*, and *Acroperus harpae* were more abundant in the acid pond. The crustaceans *Diaptomus minutus*, *Mesocyclops edax*, *Bosmina*, and seven rotifers were more abundant in the circumneutral pond. Backswimmers (*Buenoa* sp.) were abundant in Mud Pond, but apparently absent in Salmon Pond. Laboratory experiments indicated backswimmers consumed an average of 78 copepods per day, thus having an important impact on the planktonic community. The large numbers of backswimmers present in the acidic lake suggests they may have replaced fish as a significant planktivore.

Annual mean abundance of benthic macroinvertebrates in Salmon and Mud ponds was similar at depths of 0.5 m (1,370 and 1,219/m^2) but lower in Mud than in Salmon at 2-4m (2,584 and 7,144/m^2) and 9-12 m (191 and 2,973/m^2). Annual mean biomass (wet weight) was lower in Mud than Salmon at all depths (2.58 and 5.74 g/m^2 at 0.5 m, 3.99 and 11.41 g/m^2 at 2-4 m, and 1.82 and 14.46 g/m^2 at 9-12 m). Diversity was lower in Mud than Salmon. Amphipoda (*Hyalella azteca*), Mollusca (*Helisoma anceps* and *Pisidium* sp.) and Hirudinea (*Helobdella stagnalis*, *Dina* sp., *Erobdella punctata* and *Erobdella* sp.) were present in Salmon but absent from Mud. Ephemeroptera were less abundant in Mud than Salmon with *Leptophlebia* spp. occurring in both ponds and *Caenis* sp. abundant in Salmon but absent from Mud Pond. Odonata were less abundant in Mud but included the same species as Salmon. Trichoptera were more abundant in Mud but less diverse than in Salmon. The most abundant genus was *Polycentropus* with P. *smithae* present only in Mud Pond and *P. placidus*, *P. Nascotius*, and *P. cinereus* present only in Salmon Pond. Megaloptera (*Sialis* sp.) were present in both ponds. Diptera were the most abundant macroinvertebrates in both ponds. *Chaoborus punctipennis* was abundant in Salmon Pond but absent from Mud. Chironomids were more diverse in Salmon than Mud but represented a higher proportion of the total fauna in Mud than in Salmon (20% and 36% at 0.5 m, 91% and 55% at 2-4 m, and 100% and 30% at 9-12 m). Fish exclusion cage studies showed macroinvertebrates more abundant outside than inside cages in Mud but with similar abundance in Salmon. This suggests that a caging effect apparent in fishless Mud Pond may be compensated for by fish feeding in Salmon Pond and that fish may decrease the abundance of macroinvertebrates. Sweep net samples of invertebrates available to ducklings indicated that Unnamed Pond had a significantly greater abundance and biomass than Killman Pond; there were also more invertebrates in the Mud Pond sample than in the Salmon Pond samples but the difference was not significant.

Studies confirmed the apparent absence of fishes in Mud and Unnamed ponds. Salmon Pond had populations of *Salvelinus fontinalis*, *Notemigonus crysoleucas*, *Osmerus mordax*; Killman Pond had these species plus *Catostomus commersoni*, *Rhinichthys atratulus*, and *Fundulus diaphanus*. Fishes (golden shiners and rainbow smelt) were consumed by 54% of the brook trout examined in Salmon Pond, but aquatic insect larvae were very important (69% of stomachs). Diptera were the principal item in the diet of brook trout in Killman Pond. Because of the absence of fishes from the acidic ponds, it seems likely that a potential competitor of ducks for aquatic foods had been eliminated.

Imprinted black duck ducklings grew faster on acidic ponds than those on the circumneutral ponds. After 12 days, Mud Pond ducklings weighed 88 g versus 70 g for Salmon Pond ducklings; Unnamed Pond ducklings weighed 116 g

after 17 days versus 77 g for those in Killman Pond, (slopes of the growth curves were different at $p < 0.01$ for both study areas). Differences in behavior also indicated that the acidic ponds were better duckling habitat; ducklings on Mud and Unnamed ponds spent less time searching and moving, and more time feeding and resting, compared to ducklings on Salmon and Killman ponds. There was substantial overlap in the diets of trout and ducks; two of the three indices calculated indicated that ducklings sharing a circumneutral pond with fish had diets that were more similar to diets of fish than to the diets of ducklings on acidic ponds. These results support the hypothesis that ducklings and fish compete for invertebrates and that, under certain circumstances, the negative effect of acidification on fish may produce a beneficial effect for ducklings.

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INTRODUCTION

Aquatic organisms at all trophic levels may be adversely affected by acidification, including bacteria (Gahnstrom et al. 1980), algae (Raddum et al. 1980), macrophytes (Grahn 1976, Hendrey and Vertucci 1980), zooplankton (Raddum et al. 1980, Sprules 1975), benthic invertebrates (Raddum et al. 1980 J., Okland 1980, K. Okland 1980), and fish (Muniz and Leivestad 1980, Schofield and Trojnar 1980). Effects on fish in particular have been widely reported, and fish reproduction appears to be the most sensitive process (Spry et al. 1981). Reproductive failure may result from retardation of gonadal development (Beamish 1976), failure of eggs to develop to hatching (Johansson et al. 1977), failure of apparently normal embryos to hatch (Peterson et al. 1980), or mortality of newly-hatched larvae or fry (Schofield and Trojnar 1980).

Acidification affects planktonic and benthic invertebrate communities by decreasing species diversity (De Costa 1980, Hendrey and Wright 1976, Sprules 1975, Okland 1969, Leivestad et al. 1976). Most conspicuous is the apparent replacement of groups by others which are presumably more tolerant of acidity. Daphniids, molluscs, crustaceans, Ephemeroptera, and Plecoptera are among the sensitive groups, whereas bosminids, Coleoptera, Megaloptera, Corixidae, and some Chironomidae seem unaffected by acidity (De Costa 1980, Scheider et al. 1975, Okland 1969, Leivestad et al. 1976, Raddum 1980, Hall et al. 1980).

Little is known about the effects of acidification on birds that use aquatic habitats and feed on aquatic organisms (Haines and Hunter 1982). Eriksson et al. (1983) indicated that reductions in fish populations were responsible for current declines in the production of young osprey (*Pandion* haliaetus) in Sweden. However, Eriksson (1983) also speculated that piscivorous birds that dive well below the water surface for prey (i.e. loons and mergansers) may benefit initially from acidification due to increased transparency which often accompanies lowered pH. Apparently, fish are more visible and therefore more available to diving predators even if fish are at lower densities. Obviously, such benefits are short-lived. Eradication of fish from acidified lakes would eventually mean the loss of all obligate piscivores from those lakes.

Toxic metals contained in fish and invertebrates from acidified lakes may affect birds that feed on these organisms. For example, Eriksson et al. (1980) found mercury concentrations of 684 ng/g (wet weight) in goldeneye (Bucephala clangula) eggs from an acidified lake, and 526 ng/g in eggs from a non-acidified lake polluted with mercury. Nyholm and Myhrberg (1977) and Nyholm (1981) observed impaired reproductive success among passerines nesting near acidified lakes and attributed it to aluminum exposure .

The effects of acidification on macroinvertebrates could be important to waterfowl because macroinvertebrates are important food for ducklings and egg laying females (Swanson and Meyer 1973, Reinecke and Owen 1980, Reinecke 1979). At least one group, Ephemeroptera, which is quite sensitive to acidity, is a very important duck food. Reinecke (1979) found Ephemeroptera comprised 59% of the diet of young black ducks by weight, four times more than any other food item. If Ephemeroptera or other important macroinvertebrates in a pond were eliminated by acidification, the ducklings might be unable to feed on more acid-resistant species of Coleoptera or Corixidae which may be less palatable or more difficult to catch. In this case, acidification would adversely affect waterfowl by decreasing food availability .

Conversely, studies in Scandinavia (Pehrsson 1984, 1979, 1974; Henriksson et al. 1980; Eriksson et al. 1980) suggest that ducklings might have more invertebrate food in acidified lakes because of the lack of competition with fish. Diets of ducklings and fish are similiar (Bartonek and Hickey 1969, Bartonek and Murdy 1970, Eadie and Keast 1982).

Aquatic plants could play a variety of roles in this system. They may be used directly by waterfowl as food (Cottam 1939, Martin and Uhler 1939) and cover (Ringelman 1980), or indirectly as habitat for invertebrates (Andrews and Hasler 1944, Moyle 1961, Krull 1970).

In this paper we report on a project designed to test two alternative hypotheses:

1. Acidic precipitation can be deleterious to waterfowl because their food, populations of aquatic invertebrates and macrophytes, is reduced.

2. Acidic precipitation can be beneficial to waterfowl because it reduces fish populations that compete with waterfowl for food.

We chose to work on the black duck Anas Rubripes because there has been great concern over long-term declines in its population (Spencer 1981), and because its breeding range coincides with an area of North America that is vulnerable to the effects of acidic deposition (Haines and Hunter 1982).

STUDY AREA

The study focused on two pairs of oligotrophic, headwater ponds: Salmon and Mud, and Killman and Unnamed. Salmon Pond and Mud Pond were only 120 m apart and similar physically (Table 0.1), but Salmon (pH 6.3) supported a significant fish population and Mud Pond (pH 4.5) had no fish. The second pair, Killman Pond (pH 6.5) and Unnamed Pond (pH 4.8) were 14 km apart and also physically similar, but again the circumneutral pond had fish and the acidic pond was fishless. All aspects of the study were undertaken at Salmon and Mud Ponds; certain aspects were replicated at Killman and Unnamed Ponds.

Table 0.1. Physical and chemical[a] characteristics of the study ponds.

	Salmon	Mud	Killman	Unnamed
Latitude	44°38'	44°38'	45°12'	45°11'
Longitude	68°04'	68°05'	68°03'	68°11'
pH	6.3	4.5	6.5	4.8
Alkalinity (ueq/l)	44	-45	83	-20
Conductance (umhos/cm)	22	33	30	18
Calcium (ueq/l)	68	23	110	20
Total aluminum (ppb)	13	344	-	34
Total phosphorous (ppb)	11	2	NA	NA
Area (ha)[b]	2.4	1.6	9	8
Maximum depth (m)[b]	11	14	8	7
Secchi depth (m)	5.3[c]	5.6[c]	2.8[d]	7[d]

[a] Water chemistry values recorded from October or November samples by Haines et al. (1983).
[b] Values from M.D.I.F.W. Lake Surveys.
[c] Values recorded by J. S. Kahl (unpubl. data).
[d] Values recorded by the authors, total phosphorous recorded 9 July 1984.
NA = Not available.

1. AQUATIC MACROPHYTES

INTRODUCTION

Many species of aquatic biota are affected by acidification (Haines 1981) but the impacts on aquatic macrophytes have not been extensively quantified. Researchers in Sweden noted that, in some acidified lakes, plants such as _Isoetes_ spp. and _Lobelia dortmanna_ had been replaced by a mat of _Sphagnum_ (Grahn 1976, Hultberg and Grahn 1976). This predominance of _Sphagnum_ has been noted in some North American lakes (Hendrey and Vertucci 1980, Roberts et al., in press), but it is apparently not a general phenomenon. A positive correlation between pH and macrophyte species richness has been reported by workers in New York (Roberts et al. in press) and Ontario (Wile et al., in press). The Ontario study also measured macrophyte biomass in three lakes; the most acidic lake had the highest biomass. In this section we report on a survey of aquatic macrophyte biomass and species richness in the four study lakes. Macrophytes are important as food and cover for ducks and as habitat for invertebrates.

METHODS

In each pond, we measured the width of two vegetation zones along 10-24 transects. The shallow zone extended from shore to the outer limit of emergent and floating plants and the submerged zone was where only submerged plants occurred. Macrophytes were sampled in late July on ten transects spaced equidistantly around each pond. Two 0.25-m^2 quadrats were randomly located along each transect, one in each zone. SCUBA divers removed all the vegetation from each quadrat and the samples were sorted by species, washed to remove detritus, dried at 57°C for 7 days, and weighed. We calculated mean biomass for each species in each pond by weighting sample means by the area of the zone in which they were collected. Diversity was estimated by the Shannon-Wiener index. We searched extensively for additional species not found in the quadrat collections. These are included in the species lists but could not be assigned a realistic importance value for the diversity indices. Voucher specimens for each species from each pond have been deposited in the Herbarium of the University of Maine at Orono.

RESULTS AND DISCUSSION

Twenty two species of macrophyte were recorded and all 22 were found in the circumneutral ponds; they had 14 and 15 species each (Table 1.1). The two acidic ponds had only 11 species, with 10 and 6 each in the two ponds. These results are consistent with those of Roberts et al. (in press) and Wile et al. (in press) who found a negative correlation between pH and species richness.

There was tremendous variation in the relative abundance of different species with *Eriocaulon septangulare* dominating all four ponds. In Salmon Pond, *E. septangulare* comprised 96% of the biomass and consequently the diversity index was low compared to Mud Pond where there were five fewer species but *Eriocaulon* comprised only 60%; i.e. the eveness component of the diversity index outweighed the richness component. Killman and Unnamed ponds had similar diversity indices despite a difference in species richness because eight of the species in Killman Pond were not found in the quadrats and thus not included in the diversity index.

The two acidic ponds had intermediate levels of macrophyte biomass and one circumneutral pond--Killman--had the lowest biomass among the four ponds, while the other--Salmon--had the highest. Total macrophyte biomass appears to be controlled principally by lake transparency. Killman Pond, with the lowest macrophyte biomass, had a Secchi disc reading of 2.8 m compared with values above 5 m for the other ponds. These results are quite different from those of Wile et al. (in press) who reported a far greater biomass in an acidic pond than in two circumneutral ponds. They speculated that a shift in primary production from the pelagic to the benthic zone may be a general consequence of lake acidification. Our data show that this is not always the case; obviously more surveys or experimental work is needed.

Table 1.1. Aquatic plants identified from the study ponds.

	Mean g/m^2 for each species			
Aquatic Plants Identified	Salmon	Mud	Killman	Unnamed
Sphagnaceae				
Sphagnum sp.	0.48	8.85		
Hypnaceae				
Drepanoclaudus sp.			0.19	
Equisetaceae				
Equisetum fluviatile L.			p[a]	
Isoetaceae				
Isoetes sp.	0.28			
Sparganiaceae				
Sparganium angustifolium Michx.	0.14		0.03	
Sparganium sp.	p	p		p
Zosteraceae				
Potamogeton epihydrus Raf.	0.02		0.03	
Potamogeton confervoides Reichenb	p	2.31		
Cyperaceae				
Eleocharis sp.			p	
Scirpus sp.			p	
Eriocaulaceae				
Eriocaulon septangulare With.	51.72	20.28	9.66	52.94
Pontederiaceae				
Pontederia cordata L.	p	p	p	0.06
Juncaceae				
Juncus brachycephalus Engelm.			p	
Nymphaeaceae				
Nuphar variegatum Engelm.	p	0.73	p	2.81
Nymphae odorata Ait			p	p
Holoragaceae				
Myriophyllum verticillatum L.	0.22	0.01		
Myriophyllum tenellum Bigel.	0.05			
Gentianaceae				
Nymphoides cordata (Ell.) Fern.	0.24	p		

Table 1.1. Concluded.

	Mean g/m^2 for each species			
Aquatic Plants Identified	Salmon	Mud	Killman	Unnamed
Scrophulariaceae				
Unidentified			p	
Lentibulariaceae				
Utricularia intermedia Hayne	0.39			
Utricularia vulgaris L.	p	1.61	3.99	
Campanulaceae				
Lobelia Dortmanna L.	4.32	p	0.11	18.54
# or Species	15	10	14	6
Total Biomass	157.86	33.80	14.00	74.61
Diversity Index	0.21	1.07	0.74	0.74

[a] Present in the pond but not collected in the biomass samples.

2. ZOOPLANKTON

INTRODUCTION

Several authors have studied the effects of pH on zooplankton community structure. Sprules (1975a, Sprules 1975b), Fryer (1980), Nilsson (1980), Yan and Strus (1980), Confer et al. (1983) and Keller and Pitblads (1984) all reported reductions in crustacean species richness with pH. Roff and Kwiatkoiwski (1977), Crisman et al. (1980), and Raddum et al. (1980) reported reductions in total (crustacean and rotifer) zooplankton species richness. Crisman et al. (1980) showed a small decrease in total zooplankton density with pH. Confer et al. (1983) stated crustacean biomass decreased with pH, but the authors chose not to include an acid lake (pH 4.7) in their calculations. This lake had the second highest biomass of the lakes sampled and distorted the relationship between biomass and pH reported. Yan and Gieling (1985) reported a decrease in total zooplankton biomass and a coincident increase in rotifer biomass with decreasing pH.

Brett (1985) in a recent survey of 22 lakes in Maine, reported reductions in rotifer species richness and density with pH. Crustacean species richness and density did not have a significant correlation with pH, although the crustacean community of lakes below pH 5.0 consisted almost exclusively of five acid tolerant zooplankters. Fish fry density and total phosphorus had significant positive correlations with rotifer species richness and density. Fish fry density had a highly significant positive correlation with pH and was probably to some extent controlled by pH. There was significantly less total phosphorus; in the low pH lakes than in the more neutral lakes. These relations indicate pH, fish predation which is affected with pH, and total phosphorus (which is low in acid lakes) all affect zooplankton community structure in the Maine lakes sampled.

Several possible explanations for the changes in zooplankton community structure with pH have been proposed. Low pH has been reported toxic to zooplankters by several investigators (Davis and Ozburn 1969; Pots and Fryer 1979; Parents and Cheetham 1980; Havas and Hutchinson 1982) but these studies have dealt mainly with these genus Daphnia. Metals which are often high in acidified waters have been reported to have toxic effects on crustacean zooplankters (Biensinger and Christensen 1972; Baudowin and Scoppa 1974; Havas 1980; Havas and Hutchinson 1982).

Fish predation has well documented effects on zooplankton community structure (Brooks and Dodson 1965) and changes in predator community coincident with reductions in pH has been suggested as a major determinant of zooplankton community structure (Eriksson et al. 1979).

Research by Pejler (1983) indicates the highest number of zooplankton species is expected in moderately oligotrophic to moderately eutrophic lakes, with ultraoligotrophic and hypertrophic lakes depauperate in species. Acid lakes are generally low in dissolved nutrients, and Kwaitkowski and Roff (1976) reported changes in the phytoplankton with decreasing pH, potentially altering food availability for zooplankton.

This study compares the zooplankton communities of two ponds that lakes which are very similar in size and morphology and are located only 200 m apart. It is assumed that many of the differences noted between the zooplankton communities of these ponds are attributable to chemical and biological differences between the ponds. Direct effects of pH and water chemistry; secondary affects of pH and water chemistry (such as differing predatory regimes), altered food availability, and differences in the nutrient content of these ponds may all be important in determining zooplankton community structure.

The distribution and abundance of the backswimmer, Buenoa sp., was also studied. Backswimmers feed on small invertebrates, such as mosquito larvae, water boatman, and zooplankton, piercing their prey and sucking the body contents; they prefer organisms that are usually or always in the water column (Gittleman 1975; Gittleman and Bergstrom 1977). They are free swimming, usually at depths of 2-25 cm (Gittleman and Bergstrom 1977), and are adapted for quick lunges and rapid acceleration to overtake and capture prey (Gittleman 1974; Gittleman 1976). They live principally in temporary and permanent ponds with characteristically large littoral zones (Gittleman and Severance 1975). Inasmuch as they have been shown to be abundant in the absence of fish and scarce in the presence of fish, they are probably highly susceptable to fish predation (Hurlbert and Mulla 1981).

METHODS

Zooplankton Sampling

The littoral zones of both the acid and circumneutral ponds were sampled for zooplankton on four dates, June 21, July 7, July 21, and August 8, 1983. On each date, zooplankton samples were collected from eight fixed points around each pond in water 1 to 2 m deep. Samples were collected with a 1-m plexiglass tube held vertically in the water column and consisted of 8.34 l of lake water. Zooplankters were removed from the water with the filter house of a Rohde sampler with a 64µm screen and preserved in 1% lugols. Species were identified based on keys of Edmondson (1959) and Pennack (1978). Differences in zooplankton densities between the two ponds were assessed using Duncan's multiple comparison two-way analysis of variance.

Backswimmer Sampling

Relative abundance of *Buenoa* sp. in Mud and Salmon ponds was assessed on 27 September, 1983 on the basis of catch per unit of effort with dip net samples taken in the littoral zone and tow net samples in the pelagic zone. The littoral zone was sampled three times during passes through the entire littoral zone of each pond and the pelagic zone was sampled three times by pulling a tow net through the middle of each pond. Each sampling period lasted 15-20 min.

To estimate potential feeding rates of *Buenoa* sp., 50-100 backswimmers were placed in three 20-l aquaria stocked with *Diaptomus minutus* (the dominant zooplankter in Mud Pond), at the rate of 1440 L^{-1}. Feeding studies lasted 50 hr (alternating 12 hr light: 12 hr dark). At about 3-hr intervals during the 12-hr light period of the experiment, the contents of the aquaria were mixed, to stir pierced *D. minutus* off the bottom, and 125 ml samples of water were collected by immersing a bottle in various parts of aquaria until the bottle was filled. Samples were also taken in three control aquaria containing only *D. minutus* to measure any negative affects of laboratory conditions on these animals. Samples were examined under a microscope and all *D. minutus* observed were recorded as pierced or not pierced. Using these data, we estimated the percentage of zooplankters pierced at each sampling time and calculated an average consumption rate per backswimmer.

RESULTS AND DISCUSSION

Mud Pond and Salmon Pond were similar in size, morphology, color and most major ions and dissimilar in pH, alkalinity, calcium, aluminum, sulfate and total phosphorus (Brett 1985). In addition, Mud Pond is fishless while Salmon Pond has three species of fish with moderate densities of the zooplanktivorous golden shiner (*Notemigonus crysoleucas*). pH, total phosphorus, and the density of planktivorous fish have been shown to be important in structuring zooplankton communities in Maine lakes of similar size and morphology (Brett 1985).

During the sampling period, 18 species of zooplankton were identified from the acid pond and 20 from the circumneutral pond. Sixteen species were found in both ponds. The two zooplankters found only in the acid pond were the cladocerans, *Acroperus harpae* and *Chydorus* sp,. The four found only in the circumneutral pond were the cladocerans, *Holopedium gibberum* and the rotifers, *Kellicottia longispina*, *Filinia longiseta*, and *Polyarthra remata* (Table 2.1).

Table 2.1. Average density per 10 liters for 32 samples in an acidic pond (Mud Pond) and a circumneutral pond (Salmon Pond); from Brett (1983).

	Acid (Mud Pond)	Circumneutral (Salmon Pond)	Significance $p < x$
Copepoda			
Diaptomus minutus	25.70	79.37	.001
Mesocyclops edax	2.54	25.83	.001
Nauphlii	126.33	107.33	NS
Cladocera			
Bosmina	5.83	118.33	.001
Diaphanosoma brachyurum	17.96	4.21	.01
Polyphemus pediculus	10.25	.33	.001
Acroperus harpae	1.25	0	.001
Daphnia sp.	0.04	0.04	NS
Holopedium gibberum	0	0.13	NS
Chydorus sp.	0.08	0	NS

Table 2.1 - continued

	Acid (Mud Pond)	Circumneutral (Salmon Pond)	Significance $p < x$
Total crustacean density excluding nauplii	63.65	228.28	.01
Rotatoria			
Keratella taurocephala	41.62	345.63	.001
Keratella cochlearis	0.04	91.62	.001
Keratella sp.	0.08	35.08	.011
Kellicottia longispina	0	1.50	.001
Polyarthra vulraris	0.04	10.50	.001
Polyarthra remata	0	1.87	NS
Asplanchna sp.	0.16	7.08	.001
Trichocerca muticrinis	0.21	9.75	.001
Trichocerca cylindrica	0.08	0.17	NS
Lecane luna	0.04	0.12	NS
Brachionus	0.29	0.04	NS
Monostyla lunaris	0.08	0.12	NS
Filinia longiseta	0	0.04	NS
Total rotifer density	42.64	503.51	.001

The acid pond had three species that were dominant (greater than 10% of total counts) and four that were common (greater than 1% of total counts) on any one sampling date. The dominant species were *Diaptomus minutus*, *Diaphanosoma brachyurum*, and *Keratella taurocephala*, and the common species were a *Mesocyclops edax*, *Bosmina coregonis*, *Polyphemus pediculus*, and *A*. *harpae*. The circumneutral pond had four dominant species, *D*. *minutus*, *Bosmina* sp., *K*. *taurocephala*, *K*. *cochlearus*, and six common species, *M*. *edax*, *D*. *brachyrum*, *Keratella* sp., *Polyarthra vulgaris*, *Asplanchna* sp., and *Trichocerca multicrinis*.

In the 32 samples taken from the acid pond, rotifer species richness ranged from zero to four species, $x = 1.6$, while crustacean species richness ranged from three to seven, $x = 4.4$. In the circumneutral lake rotifer richness ranged from two to ten species, $x = 5.25$, while crustacean richness ranged from two to six, x = 4.4. Both rotifer and crustacean density was significantly higher in the circumneutral pond.

Ten zooplankters were more abundant in the circumneutral pond. These were the acid tolerant crustaceans _Diaptomus_ _minutus_ and _Bosmina_ (Sprules 1975), the acidophilous rotifer _Keratella_ _taurocephala_ Pennak (1978), and the rotifers _Keratella_ _cochlearus_ _cochlearus_, _Keratella_ sp., _Kellicottia_ _longispina_, _Polyarthra_ _vulgaris_, _Asplanchna_ sp., and _Trichocerca_ _multicrinis_. All these rotifers except _K_. _taurocephala_ were found in low densities, <.25 individuals per 10 l, in the acid pond. The differences in the zooplankton communities of Mud Pond, pH 4.5, and Salmon Pond, pH 6.2, can probably be attributed to differences in the water chemistry and biotic communities of these ponds. Notably, the toxic affects of low pH and high aluminum, the lack of fish predation in the acid pond and differences in total phosphorus between the two ponds are probably all partially responsible for the differences noted in the zooplankton communities of these ponds.

Backswimmers

In Mud Pond, the catch of backswimmers was 199 h^{-} in the littoral zone and 42 h^{-1} in the pelagic zone. No backswimmers were collected in either zone of Salmon Pond. The abundance of backswimmers in Mud Pond was probably a result of the absence of fish predators, which in turn was a result of the toxic effects of low pH. Data collected from 23 lakes in Maine indicates nektonic invertebrates can have very high densities in fishless or lakes with sparse populations of fish. All the fishless lakes sampled lacked fish presumably because of very low pH, (<5.0). The most common nektonic invertebrate collected in the acid fishless lakes were the backswimmers _Buenoa_ and _Notonecta_ the distisid larvae _Grapohoderus_ sp.

Hydracarinids corixids and the trichopteran _Tricaenodes_ sp. (Brett 1985). Dense nekton communities have also been observed in acid fishless lakes in Scandinavia (Henrikson and Oscarson 1978).

The laboratory feeding experiment demonstrated that _Buenoa_ sp. is a significant predator on copepods, each insect consuming an average of 78 _Diaptomus minutus_ per day. Mortality of _D. minutus_ in the control aquaria was 1% mortality over the 50-h period. As judged by observations in 22 lakes in Maine, _Buenoa_ sp. does not become a significant member of the nektonic community until early to mid July (M. Brett, Department of Zoology, University of Maine, unpublished data).

The abundance of the planktivorous backswimmer and the absence of fish planktivores presumably had marked effects on the zooplankton community structure and diversity of Mud Pond. A significant part of the variation noted in zooplankton communities of acidified waters may be the result of changes in the biotic communities of those waters; the toxic effects of acidity probably also play a significant role in determining species diversity and density. In this sense, backswimmers in such acidic waters may take on the predatory role assumed by fishes in circumneutral waters, replacing fish as the major planktivore and influencing the composition and size distribution of zooplankton communities.

3. BENTHIC MACROINVERTEBRATES OF MUD AND SALMON PONDS

INTRODUCTION

Benthic macroinvertebrates are important in aquatic ecosystems because of their role in the processing of living and dead plant material and because of their importance as food for fishes and waterfowl. Much of the available literature on effect of acidification on this group has been reviewed by Haines (1981) and is in the form of faunal surveys which relate distribution to lake pH. Relatively low abundance, biomass and diversity are characteristic of the benthic madroinvertebrates of acidified lakes.

In this study benthic macroinvertebrates were sampled in Mud and Salmon Ponds in 1982 and 1983. Standing stock and biomass of total macroinvertebrate are reported for the two ponds. The invertebrates have been identified to genus and species where possible and the species assemblages of both ponds have been described. The distribution of invertebrates in relation to lake pH reported in this study has been compared with that found by other workers.

The impact of fishes on macroinvertebrates was studied by comparing standing stock inside and outside of fish exclusion cages in Salmon Pond which contained fish and in Mud Pond which was fishless.

METHODS

Benthic macroinvertebrates were sampled at three depths (Table 3.1).

Table 3.1. Benthic macroinvertebrate sampling methods used in Mud and Salmon Ponds.

Method	Area Sampled	Form Sampled	Water Depth	Number of Replicates	Sampling Frequency	1982	1983
Stovepipe Cylinder	$0.2m^2$	Benthos	0.5m	5	Monthly May-Oct.	X	X
Ekman Grab	$0.02m^2$	Benthos	2-4m	10	Monthly May-Oct.	X	X
Ekman Grab	$0.02m^2$	Benthos	9-12m	10	Monthly May-Oct.	X	
Emergence Trap	$0.46m^2$	Adult insect emergence	.5m	3	Cleared weekly May-Oct.		X

The samples were preserved in the field in 80% ethyl alcohol, returned to the laboratory, washed through a #60 sieve, and the organisms removed from the debris by hand sorting. Biomass (blotted wet weight) was recorded for the 1982 benthic samples. Organisms were identified and enumerated. Identification was to species or to the lowest possible taxon. Chironomidae were identified to genus only from the 1982 samples. Insects from the emergence traps were identified and enumerated. All quantitative results were transformed from numbers/sample to numbers/m^2 for uniformity.

Six 0.9 X 1.8 m fish exclosure cages were placed in the ponds on 16 July 1983, three in Mud and three in Salmon. The cages were of aluminum screening (1 mm aperture) supported on aluminum frames. Cages were weighted with cement blocks and extended ca. 15 cm into the substrate and ca. 15 cm above the water surface. On 20 October 1983 the macroinvertebrates were sampled by taking three Ekman grabs inside each exclosure and three outside.

RESULTS

Biomass

The biomass in Mud Pond was consistently less than in Salmon Pond (Table 3.2). At a depth of 0.5 m, the mean annual biomass in Mud Pond was 45% of that in Salmon, at 2 - 4 m 35% of that in Salmon and at 9-12 m 13 %.

Table 3.2. Mean benthic biomass (g/m^2 blotted wet weight) of total macroinvertebrates in Mud and Salmon Ponds in 1982 at depths of 0.5 m, 2-4 m and 9-12 m.

Sampling Dates	0.5 m			2-4 m			9-12 m		
	Mud		Salmon	Mud		Salmon	Mud		Salmon
6/9	1.15	*	5.65	2.35	***	10.29	1.47	***	20.90
7/5	2.35	ns	5.35	4.70	***	14.11	1.80	*	4.70
8/3	2.60	*	6.65	3.53	**	7.64	0.29	***	7.35
8/31	2.85	ns	5.70	4.70	***	14.11	0.88	***	9.99
10/4	3.95	ns	5.35	4.70	*	10.88	1.47	***	14.70
Annual X	2.58		5.74	3.99		11.41	1.82		14.46

Values separated by an * are significantly different; t-test * p < / =0.05, ** p < / = 0.01, *** p < / = 0.001, ns = not significant.

Standing Stock

There was no consistent difference in standing stock between the two ponds at a depth of 0.5 m in 1982 or 1983 (Table 3.3 and 3.4). However, the standing stock was less in Mud than in Salmon at 2-4 m and at 9-12 m. At 2-4 m, the mean annual standing stock in Mud was 36% of that in Salmon in 1982 and 37% in 1983 and at 9-12 m 6% of that in Salmon in 1982.

Table 3.3. Mean total benthic macroinvertebrate standing stock (n/m^2) from Mud and Salmon Ponds on sampling dates in 1982 at depths of 0.5 m, 2-4 m and 9-12 m.

Sampling Dates	0.5 m			2-4 m			9-12 m		
	Mud		Salmon	Mud		Salmon	Mud		Salmon
6/9	273	**	1,001	1,735	***	4,880	338	***	4,374
7/5	2,039	*	1,379	5,145	ns	6,027	353	ns	1,323
8/3	1,246	ns	1,082	1,882	*	3,734	29	*	1,528
8/31	959	**	453	1,865	***	12,201	38	***	1,940
10/4	1,195	ns	1,165	2,293	**	8,879	206	***	5,704
Annual $\overline{X}$	1,370		1,219	2,584		7,144	191		2,973

Statistical conventions as in Table 3.2.

Table 3.4. Mean total benthic macroinvertebrate (n/m^2) standing stock from Mud and Salmon Ponds on sampling dates in 1983 at depths of 0.5 m and 2-4 m.

Sampling Dates	Depth					
	0.5 m			2-4 m		
	Mud		Salmon	Mud		Salmon
5/31	553	ns	359	906	**	4,281
6/29	1,029	ns	1,656	2,176	*	4,525
7/19	1,268	*	2,374	2,769	***	11,442
8/16	1,446	ns	1,263	4,025	***	11,563
9/14	3,095	*	1,674	7,041	***	17,787
10/12	1,510	ns	2,770	7,744	***	17,899
Annual $\overline{X}$	1,484		1,683	4,110		11,250

Statistical conventions as in Table 3.2.

Distribution and Abundance of Taxa

There were substantial differences between Mud and Salmon ponds in the distribution and relative abundance of taxa (Table 3.5).

Table 3.5. Mean annual standing stock (n/m^2) of benthic macroinvertebrate taxa in Mud and Salmon Ponds in 1982 and 1983.

Taxa	Mud		Salmon	
	1982	1983	1982	1983
Depth - 0.5 m				
Amphipoda	0	0.3	134	268
Ephemeroptera	5	31	160	159
Odonata	25	47	160	305
Megaloptera	10	26	10	10
Trichoptera	40	72	40	19
Chironomidae	970	1,198	440	761
Ceratopogonidae	40	41	20	47
Mollusca	0	0	60	15
Oligochaeta	11	5	38	51
Depth - 2 - 4 m				
Amphipoda	0	10	1,846	2,852
Ephemeroptera	0	9	88	265
Odonata	29	97	235	329
Megaloptera	29	229	59	258
Trichoptera	29	71	0	21
Chironomidae	2,352	3,481	3,969	5,995
Ceratopogonidae	88	27	323	662
Mollusca	0	3	470	753
Oligochaeta	24	283	216	180
Depth - 9 - 12 m				
Chironomidae	191		941	
Chaoboridae	0		1,764	
Oligochaeta	0.5		38	

Amphipoda

Amphipoda were absent from samples in Mud Pond or present only in low numbers (Table 3.5). The only species collected was *Hyalella azteca* and its distribution is shown in Table 3.6. *H. azteca* was abundant in all samples from 0.5 m and 2-4 m in Salmon Pond in 1982 and 1983. It was absent from Mud Pond in 1982 but present in low numbers at depths of 0.5 m and 2-4 m in 1983.

Table 3.6. Mean standing stock (n/m^2) of *Hyalella azteca* in Mud and Salmon ponds in 1982 and 1983 at depths of 0.5 m and 2-4 m.

Sampling Dates	0.5 m		2-4 m	
	Mud	Salmon	Mud	Salmon
1982				
6/9	0	167	0	1,073
7/5	0	102	0	858
8/3	0	92	0	1,005
8/31	0	55	0	4,063
10/4	0	252	0	2,231
Annual $\bar{X}$	0	134	0	1,846
1983				
5/31	0	169	21	1,361
6/29	0	427	3	620
7/19	0	403	9	2,490
8/16	0	158	0	5,133
9/14	0	137	21	4,236
10/4	2	312	6	3,266
Annual X	0.3	268	10	2,851

Ephemeroptera

Ephemeroptera were present in lower numbers in Mud than in Salmon (Table 3.5). Five genera were present at 0.5 m and 2-4 m in Salmon Pond and two genera were present in Mud Pond (Table 3.7).

Table 3.7. Mean standing stock (n/m^2) of genera of Ephemeroptera in Mud and Salmon ponds in 1982 and 1983 at depths of 0.5 m and 2-4 m.

	0.5 m				2-4 m			
	Mud		Salmon		Mud		Salmon	
Genera	1982	1983	1982	1983	1982	1983	1982	1983
Caenis	0	0	100	116	0	0	58	214
Ephemerella	0.2	2	4	2	0	1	0	1
Leptophlebia	5	27	59	41	0	9	21	32
Siphlonurus	0	0	0.2	0	0	0	0	0
Stenacron	0	0	0	0.2	0	0	0	0
Annual $\bar{X}$	7.2	29	163.2	159.2	0	10	79	247

Caenis, the most abundant genus, was present only in Salmon Pond and never collected from Mud Pond. *Leptophlebia* was present in both ponds although in lower numbers in Mud than Salmon. *Ephemerella*, *Siphlonurus* and *Stenacron* were only occasionally collected.

Odonata

Odonata were present at 0.5 m and 2-4 m in both ponds but in substantially lower numbers in Mud than Salmon (Table 3.5).

Table 3.8. Standing stock (g/m^2) of species of Odonata in Mud and Salmon ponds in 1982 and 1983 at depths of 0.5 m and 2-4 m.

	0.5 m				2-4 m			
	Mud		Salmon		Mud		Salmon	
Heading	1982	1983	1982	1983	1982	1982	1982	1983
Anisoptera								
Gomphidae								
Gomphus exilis	0.6	1.2	5.0	1.5	0	0.5	6.4	10.8
Aeshnidae								
Aeshna eremita	1.0	0.7	3.0	1.6	0	0	0	0.6
Corduliidae								
Cordulia shurtleffi	3.6	12.7	53.8	30.2	6.4	13.7	66.4	57.6
Libellulidae (unidentified)	3.0	3.3	0	38.8	9.4	44.1	0	48.5
Ladona julia	0	0	0.2	0.2	0	0	0	0
Leucorrhinia glacialis	18.4	51.5	18.8	165.4	10.6	35.8	154.0	118.8
Libellula sp.	0	0	5	1.5	0	0	4.1	1.5
Zygoptera								
Lestidae								
Lestes eurinus and *L. vigilax*	0.4	2.6	0	0.6	0	0	0	0
Coenagrionidae (unidentified)	0	1.0	1.0	7.0	0	2.5	3.5	22.3
Agria fumipennis violacea	0	0	5.4	4.2	0	0	0.6	5.8
Enallagma aspersum	0.4	7.8	30.3	51.9	0	3.4	35.9	25.2

The assemblages of Odonata were similar in the two ponds (Table 3.8). Seven species were common to both ponds and *Cordulia shurtleffi*, *Leucorrhinia glacialis* and *Enallagma aspersum* were the most abundant species in both ponds. *Ladona julia*, *Libellula* sp. and *Agria fumipennis violacea* were present only in Salmon Pond.

Megaloptera

Sialis sp. was present in both Mud and Salmon ponds at 0.5 m and 2-4 m in 1982 and 1983 (Table 3.5).

Trichoptera

Trichoptera were present in both ponds at 0.5 m and 2-4 m and were more abundant in Mud than Salmon Pond (Table 3.5). Larvae were identified to genus and adults collected in the emergence traps to species. Fifteen genera of larvae were present in samples from Salmon Pond and nine in those from Mud Pond (Table 3.9).

Table 3.9. Genera of Trichoptera larvae present in Mud and Salmon ponds in 1982 and 1983.

	Mud	Salmon
Agarodes		X
Agrypnia	X	X
Anabolia		X
Banksiola	X	X
Ceraclea		X
Cheumatopsyche	X	
Lepidostoma		X
Limnephilus	X	X
Mystacides		X
Nemotaulius		X
Ocetis		X
Oxyethira	X	X
Phyganea		X
Platycentropus	X	
Polycentropus	X	X
Ptilostomis	X	
Pycnopsyche		X
Triaenodes	X	X
	9	15

Most of these taxa were present in numbers too low to allow quantitative comparison. *Polycentropus* was the most abundant genus and accounted for the higher standing stock of Trichoptera in Mud Pond (Table 3.10). Based on adults from the emergence traps, *P. smithae* appears to have been the only species present in Mud Pond but it was not collected from Salmon Pond. *P. cinereus* and *P. nascotius* were present in Salmon Pond but not collected from Mud Pond.

Table 3.10. Mean annual standing stock (n/m^2) of *Polycentropus* larvae in Mud and Salmon ponds in 1982 and 1983 at depths of 0.5 and 2-4 m.

0.5 m				2-4 m			
Mud		Salmon		Mud		Salmon	
1982	1983	1982	1983	1982	1983	1982	1983
27.4	62.0	5.4	2.0	40.6	80.0	2.5	5.3

Diptera

Diptera was the most abundant order in the ponds with the Chironomidae, Ceratopogonidae and Chaoboridae the most abundant families.

Chironomidae

Chironomidae was the most abundant single taxon in both ponds and present at all sampling sites (Table 3.5). However, the abundance of this group relative to other macroinvertebrates was higher in Mud than Salmon Pond. At 0.5 m, chironomids represented 70% (1981) and 81% (1983) of the total macroinvertebrates in Mud Pond but only 36% (1982) and 42% (1983) in Salmon Pond. At 2-4 m, chironomids represented 91% (1982) and 85% (1983) of the total in Mud and 55% (1982) and 53% (1983) in Salmon, at 9-12 m 100% in 1982 in Mud and 30% in Salmon.

Chironomids were identified to genus in 1982 but not in 1983 (Table 3.11).

Table 3.11. Mean annual standing stock (n/m^2) of genera of Chironomidae at the three sampling sites in 1982 at depths of 0.5 m, 2-4 m and 9 -12 m.

Taxa	0.5 m		2-4 m		9-12 m	
	Mud	Salmon	Mud	Salmon	Mud	Salmon
Tanypodinae						
Ablabesmyia	30	53	308	108	0	0
Clinotanypus	0	3	0	41	0	0
Coelotanypus	0	2	0	0	0	0
Labrundinia	0	0.4	0	2	0	0
Larsia	0	3	0	27	0	0
Natarsia	0	0	0	11	0	0
Procladius	155	147	847	126	1	239
Thienemannimyia gr.	0	35	0	156	0	0
Orthocladiinae						
Brillia	0	0.4	0	0	0	0
Cricotopus	4	5	0	2	0	0
Eukiefferiella	0.2	0.6	14	5	0	0
Heterotrissocladius	0	4	0	40	0	0
Nanocladius	0	0.4	2	2	0	0
Parametriocnemus	0	0	0	0	9	0
Psectrocladius	0	1	240	71	2	0
Zalutschia	0	0.4	9	26	0	0
Unknown	0	2	0.2	0.2	0	0
Chironomini						
Chironomus	25	11	83	7	0	530
Cladopelma	0	34	2	128	0	0
Cryptochironomus	0	1	0	11	0	0
Cryptotendipes	0	3	6	40	0	0
Dicrotendipes	107	8	76	814	0	0
Einfeldia	0	2	0	0	0	0
Endochironomus?	0.2	0	0	1	0	0
Glyptotendipes	0	0.2	0	11	0	0
Harnishia	0	4	0	0	0	0
Lauterborniella	0	78	0	25	0	0
Microchironomus	0	0	2	0	0	0
Microtendipes	0	6	0	11	1	0
Parachironomus	0	0	1	5	0	0
Paratendipes	0	3	0	0	0	0
Paralauterborniella	0	0.2	0	25	0	0
Phaenospectra	0	0	24	1	321	0
Polypedilium	8	9	100	499	2	0
Pseudochironomus	1	9	1	61	0	0
Stenochironomus	0.2	0.4	0	0	0	0
Stictochironomus	0	0	2	0	0	0
Tribelos	52	0.5	132	0	0	0
Xenochironomus	0	0	0	2	0	0

Table 3.11. Continued

Taxa	0.5 m		2-4 m		9 -12 m	
	Mud	Salmon	Mud	Salmon	Mud	Salmon
Unknown	28	8	333	121	0	0
Tanytarsini						
Cladotanytarsus	0	10	0	633	0	0
Microspectra	C	0.8	0	0	0	0
Paratanytarsus?	0	0	0	2	0	0
Rheotanytarsus	0	0.4	0	14	0	0
Stempellina	0	2	0	9	0	0
Stempellinella	0	1	0	1	0	0
Tanytarsus	229	138	1,086	254	0.2	0

There was a greater diversity of genera in Salmon Pond than in Mud Pond (Table 3.12).

Table 3.12. Number of genera of Chironomidae identified from Mud and Salmon ponds in 1982.

Subfamily	Mud	Salmon
Tanypodinae	2	7
Orthocladinae	7	8
Chironominae		
Chironomini	14	20
Tanytarsini	1	7
Total	24	42

Within the Tanypodinae, Procladius and Abalbesmyia were the only genera present in Mud Pond. In the Orthocladiinae, Psectrocladius was the most abundant genus in both ponds. Heterotrissocladius and Brillia were present in Salmon but not Mud Pond. In the Tanytarsini, Tanytarsus was abundant in both ponds but *Cladotanytarsus* was abundant in Salmon and absent from Mud. At 9-12 m *Procladius* and *Chironomus* were abundant in Salmon Pond and *Phaenospectra* was abundant in Mud.

Chaoboridae

Chaoborus punctipennis was the only chaoborid collected during this study, and it occurred only at 9-12 m in Salmon Pond where it was abundant (Tables 3.5 and 3.13) on all sampling dates.

Table 3.13. Mean standing stock (n/m^2) of *Chaoborus punctipennis* at 9-12 m in Salmon Pond.

	Sampling Dates				
	2 June	5 July	3 August	31 August	4 October
n/m^2	1,999	823	470	882	4,674

Ceratopogonidae

Larvae of Ceratopogonidae were present in both Salmon and Mud ponds at 0.5 m and 2-4 m. (Table 3.5).

Mollusca

Mollusca, consisting of the snail, *Helisoma anceps*, and the pisidiid clam, *Pisidium* sp., were relatively abundant at 0.5 m and 2-4 m in Salmon Pond, but absent from 0.5 and in low numbers at 2-4 m in Mud Pond (Tables 3.5 and 3.14).

Table 3.14. Mean annual standing stock (n/m^2) of Mollusca in Mud and Salmon ponds in 1982 and 1983 at depths of 0.5 m, 2-4 m and 9-12 m.

	0.5 m				2-4 m				9-12 m	
	Mud		Salmon		Mud		Salmon		Mud	Salmon
	1982	1983	1982	1983	1982	1983	1982	1983	1982	1982
Helisoma anceps	0	0	2	14	0	0.5	33	27	0	0
Pisidium	0	0	34	60	0.5	6	476	982	0	2

Oligochaeta

Oligochaetes, mainly *Lumbriculus*, were found at all sites sampled (Table 3.5).

Other Taxa

Other taxa were found in small numbers. Coleoptera (Dytiscidae and Gyrinidae) and Hemiptera (Coxididae and Notonectidae) characteristic of the neuston and nekton were taken occasionally in benthic samples from both ponds. Nematoda and Hydracarina were also present in both ponds. Turbellaria and Hirudinae (*Helobdella stagnalis*, *Dina* sp. *Erobdella punctata* and *Erobdella* sp.) were present in Salmon but not in Mud Pond. Neuroptera were taken from both ponds with *Sysira* present in Mud Pond and *Climacia* and *Sisyra* in Salmon Pond.

Emergence Traps

The Chironomidae, Trichoptera and Odonata were the most abundant insect taxa emerging at 0.5 m (Table 3.15).

Table 3.15. Total number of insects collected from the emergence traps at 0.5 m on Mud and Salmon ponds.

Taxon	Mud	Salmon
Ephemeroptera	2	14
Odonata	25	24
Neuroptera	0	14
Trichoptera	241	142
Chironomidae	702	746
Total	970	940

The total number from each pond were similar, with the Chironomidae the most abundant taxon. Trichoptera were more abundant and Odonata similar in numbers.

Fish Exclusion Cages

In Mud Pond there was a substantially lower number of macroinvertebrates inside the cage than outside (Table 3.16). In Salmon Pond, however, the numbers inside and outside the cages were approximately equal.

Table 3.16. Mean numbers of benthic macroinvertebrates per Ekman grab sample inside and outside fish exclosure cages.

	Mud			Salmon		
	$\overline{X}$	±	SD	$\overline{X}$	±	SD
Inside cages	184.2	±	29.6	6867	±	70.9
Outside cages	639.6*	±	121.8	5587	±	33.3

*p / = 0.02, ANOVA

The taxon responsible for this difference in numbers was the Chironomidae (Table 3.17).

Table 3.17. Mean numbers of major taxa of macroinvertebrates per Ekman grab sample inside and outside fish exclosure cages.

	Mud		Salmon	
Heading	Inside	Outside	Inside	Outside
Ephemeroptera	2.7	0	7.8	17.3
Trichoptera	6.7	5.7	0.6	0.3
Odonata	10.3	14.3	9.9	17.3
Chironomidae	137.8	589.3	461.0	354.3
Ceratopogonidae	15.3	11.7	57.9	15.7
Sialis	4.3	6.7	4.1	8.3
Hyallela azteca	0.1	0	74.6	114.3
Mollusca	0.1	0	39.9	25.0
Oligochaeta	4.0	4.3	19.1	1.3

Another group showing a difference in numbers inside and outside the cages were the Oligochaeta which were similar inside and outside in Mud but more abundant inside than outside in Salmon.

DISCUSSION

The lower biomass and abundance of macroinvertebrates in Mud Pond (pH 4.5) than in Salmon Pond (pH 6.3) is in agreement with studies by Scandanavian workers (Hendry et al. 1976), but it is in contrast with findings of Collins et al. (1981) who found biomasses in acidified lakes equal to or higher than those in circumneutral lakes. Collins et al. (1981) suggested that the discrepancy might be related to the higher levels of aluminum in the Scandanavian lakes.

Haines (1981) and Allison and Harvey (1981) have reviewed the occurrence of invertebrates in acidified environments and the findings of this study are generally in agreement with those of other workers with lower diversity of most groups in Mud Pond. The presence of even low numbers of amphipods in Mud Pond in 1983 was surprising and suggests that there may be annual variation in the occurrence of these organisms in marginal habitats. The genus Chaoborus shows variation in its occurrence in acidic environments. It is evident that different genera of mayflies show different tolerances of acidic conditions. We found Leptophlebia in both ponds and Caenis only in Salmon Pond. Hendry and Wright (1975) reported species of Caenis from lakes with pH 6.49 - 6.90 and Leptophlebia from pH 4.9 - 6.9, Mackay and Kersey (1985) also noted the tolerance of Leptophlebia to acidic habitats. The higher abundance of Trichoptera in Mud Pond was due to the higher numbers of Polycentropus late in the season. It is of interest that there was no overlap of species of this genus in the two ponds with P. smithae confined to Mud Pond and P. cinereus and P. nascotius confined to Salmon Pond. The tolerance of low pH of Megaloptera and Odonata shown in this study has been reported elsewhere (Haines 1981). The generic assemblages of chironomids showed similarity to those reported from other acidic lakes (Utala 1981) with diversity lower in more acidic environments and diversity decreasing with increasing depth. The dominance of *Phaenopsectra* in the deeper areas of acidic lakes has also been previously reported.

The fish exclusion cage results indicated that the presence of fish may have an impact on the abundance of macroinvertebrates. In Mud Pond, which contained no fish, there was a substantially lower number of macroinvertebrates inside the cage than outside. Chironomidae were responsible for this difference. The possibility that this "cage affect" can be attributed to restricted access by ovipositing adults has been suggested by Thorp and Bergey (1981). In Salmon Pond, however, numbers inside and outside the cages were approximately equal. We speculate that in this pond the negative influence of the fish may have counter balanced the "cage affect" seen in Mud Pond. The similar standing stock of macroinvertebrates outside the cages in Mud and Salmon Ponds is consistent with that reported in Table 3.4 for October when the exclusion traps were removed and the macroinvertebrates were sampled.

4. INVERTEBRATES OF DUCKLING FORAGING MICROHABITATS

INTRODUCTION

Although black duck ducklings eat a wide variety of invertebrates (Reinecke 1979) only a portion of the invertebrates in a pond are available to the ducklings because either their behavior (e.g. Gyrinidae) or their microhabitat (e.g. benthos) make them difficult for the ducklings to obtain. No artificial sampling device can exactly duplicate the ducklings' sampling procedure but we attempted to undertake a relatively appropriate procedure. This involved sweep-netting in those microhabitats, largely littoral vegetation, where the ducklings were foraging, at the time they were foraging.

METHODS

The duck observers sampled invertebrates daily throughout the duckling experimental periods in microhabitats where the ducklings were foraging (see Section 6). At six intervals per day, samples were collected with three 1-m sweeps of a 30 X 30 cm net held half above and half below the water surface. Invertebrates were later identified to the lowest possible taxon, counted, and their blotted wet weights measured.

RESULTS

In terms of both biomass and number of individuals, there were more invertebrates in sweep net samples from [illegible]idic ponds than from the circumneutral ponds although the differences between Mud and Salmon were not statistically significant (Table 4.1). The enormous difference in abundance between Killman and Unnamed Ponds was largely due to a very large population of chironomids in Unnamed Pond. The overall diversity of macroinvertebrates in the ponds, as measured by the number of families in each pond, was similar. However, there were profound differences in the structure of the invertebrate faunas of the ponds (Tables 4.3 and 4.3). For example, Hemiptera, especially Notonecta, were more abundant in the acid ponds. In Mud and Salmon Ponds, where detailed benthic surveys were also undertaken (see Section 3) we noted that Amphipoda, Gastropoda, and Chaoborus were abundant in the circumneutral pond and absent, or nearly so, in the acid pond.

Table 4.1. Biomass, density, and familial diversity of macroinvertebrates collected by sweep netting (mean +/- SE).

	Salmon (pH 6.3)	Mud (pH 4.5)	Killman (pH 6.2)	Unnamed (pH 4.8)
Biomass (g/m^2)	0.41 + 0.05	0.47 + 0.05	0.17 + 0.02	* 0.56 + 0.10
Density (N/m^2)	43 + 4.6	50 + 6.6	44 + 5.2	* 554 + 280.9
N	73	72	89	90
No. of families	56	51	54	61

* p </= 0.0001, t-test on data transformed data using an arcsine square-root function (Sokal and Rohlf 1969).

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Table 4.2 Invertebrates identified from sweep net samples from Mud and Salmon ponds - 1983.

Class	Order	Family	Genus/species	1983	
				Mud	Salmon
Turbellaria				4	3
Hirundinea				0	1
Oligochaeta				66	0
Crustacea	Cladocera			13	0
	Copepoda			18	0
	Amphipoda	Talitridae	*Hayalella azteca*	0	185
	Hydracarina			199	12
Insecta	Collembola	Isotomidae		4	1
		Sminthuridae		49	15
		UN-ID		0	0
	Plecoptera	Leuctridae	*Leuctra*	1	1
	Ephemeroptera	Caenidae	*Caenis*	0	2
		Leptophlebiidae	*Leptophlebia*	29	0
		Ephemerellidae	Ephemerella (*Eurylophella*) *temporalis*	33	44
			E. (*Eurylophella*) *verisimilis*	0	3
			E (*Eurylophella*)	5	1
			UN-ID	1	0
		Heptageniidae	*Arthroplea bipunctata*	3	0
	Odonata	Aeshnidae	*Boyeria*	7	0
			Aeshna	1	1
			UN-ID	11	1
		Libellulidae	*Leucorrhinia*	28	0
			UN-ID	9	6
		Corduliidae	*Somatochlora*	1	0
		Gomphidae		0	2
		Coenagrionidae	*Coenagrion*	1	1
			Enallagma	2	21
			Ischnura	1	4
			Nehalennia	1	0
			UN-ID	2	9
		Lestidae	*Lestes*	1	0
		UN-ID		1	0

39.

Table 4.2 Continued.

Class	Order	Family	Genus/species	1983	
				Mud	Salmon
	Lepidoptera			3	6
	Coleoptera	Haliplidae	Peltodytes	6	0
		Dytiscidae	Grophoderus	8	0
			Hydroporus	11	0
			Hydrovatus	1	0
			Hygrotus	2	0
			UN-ID	3	0
		Gyrinidae	Dineutus	2	0
			Gyrinus	2	1
		Staphlinidae	(T)[a]	1	1
		Cantheridae	(T)	2	1
		Anthicidae	(T)	1	0
		Elateridae	(T)	0	3
		Buprestidae	(T)	1	0
		Helodidae	Cyphon	0	29
		Chrysomelidae	(T)	1	1
		Coccinellidae	(T)	0	1
		Curculionidae	(T)	1	0
		UN-ID		0	2
	Diptera	Tipulidae	Pilaria	1	0
			Phalacrocera	2	0
			Pseudolimnophilia spp.	1	0
			UN-ID	1	1
		Dixidae	Dixella	0	1
		Culicidae	(T)	0	2
		Simuliidae	(T)	2	9
		Chironomidae		230	65
		Ceratopogonidae	Atrichopogon	1	0
			Bezzia/Palpomyia	7	0
			Culicoides	7	0
			UN-ID	74	81
		Empididae	Hemerodromia	1	4
			UN-ID	6	60
		Cecidomyidae	(T)	1	1
		Tachinidae	(T)	1	1
		UN-ID		21	20

40.

Table 4.2. Concluded.

Class	Order	Family	Genus/species	1983	
				Mud	Salmon
	Hemiptera	Gerridae		1	7
		Veliidae	Microvelia	0	1
		Notoenectidae	Notenecta	9	2
		Nepidae	Ranatra	1	0
		Corixidae	Sigara	2	1
	Homoptera	Cercopidae	(T)	0	1
		Cicadelidae	(T)	0	2
		Chermidae	(T)	9	82
		Aphididae	(T)	2	8
	Megaloptera	Corydalidae	Chauloides rastricornis	3	1
		Sialidae	Sialis	3	22
	Neuroptera	Sisyridae	Sisyra	0	48
			Climacia	0	1
	Trichoptera	Hydroptilidae	Hydroptila	0	2
			UN-ID	0	1
		Polycentropodidae	Polycentropus spp.	59	5
		Psychomyidae	Lype diversa (T)	0	4
		Molannidae	Molanna tryphena (T)	0	3
		Phryganeida	Banksiola spp.	3	0
		Limnephilida	Anabolia spp.	1	3
			Limnephilis spp.	1	1
		Sericostomatidae	Agarodes spp.	0	2
	Hymenoptera	Pamphiliidae	(T)	0	1
		Ichneumonidae	(T)	1	1
		Formicidae	(T)	4	3
		UN-ID		1	1
	Exuvia	UN-ID		p[b]	p
Aranea	Arachnidae	(T)		30	77
	Pelecypoda	Sphaeriidae		0	6
Egg mass	UN-ID			13	0
Fish				0	1

[a] (T) indicates only terrestrial form identified.
[b] p indicates present but not counted.

Table 4.3. Invertebrates identified from sweep net samples taken from from Killman Pond and Unnamed Pond (N=90/pond).

Macroinvertebrates	Killman	Unnamed
OLIGOCHAETA		
Hirudinea (A)[a]	4	
Lumbriculidae (A)	4	1
Tubificidae (A)	74	
CRUSTACEA		
Cladocera (A)	1	2
Hydracarina (A)	55	36
Amphipoda (A)	214	
INSECTA		
Coleoptera		
Unidentified Family (T)[b]		1
Cantheridae (T)	1	
Chrysomelidae (T)		1
Dytiscidae (A)		55
Elmidae (A)	1	
Elateridae (T)		1
Gyrinidae (A)	6	1
Haliplidae (A)	4	
Helodidae (A)	2	ex[c]
Lyctidae (T)		1
Melandryidae (T)		1
Staphylinidae (T)		4
Collembola		
Unidentified Family (T)		2
Isotomidae (T)	2	4
Sminthuridae (T)	25	38
Diptera		
Unidentified Family (T)	15	4
Unidentified muscoid fly (T)		2
Unidentified Nemotocera (T)		1
Anthomyzidae ? (T)		1
Cecidomyidae (T)		1
Ceratopogonidae (T and A)	113	209
Chironomidae (T and A)	84	1559
Conopidae (T)		1
Culicidae (T)	12	34
Empididae (T)		1
Mycetophilidae (T)		ex
Sciaridae (T)	1	
Simuliidae (T)	13	28

Table 4.3. Continued.

Macroinvertebrates	Killman	Unnamed
Ephemeroptera		
Unidentified Family (T)	1	ex
Caenidae (A)	4	
Ephemerellidae (T and A)	331	
Ephemeridae (T and A)	1	
Heptageniidae (T)	2	
Leptophlebiidae (T and A)	5	1
Hemiptera		
Unidentified Family (T)	ex	3
Corixidae (A)	2	9
Gerridae (A)	14	120
Mesoveliidae (A)	1	119
Notonectidae (A)	3	525
Homoptera		
Unidentified Family (T)	1	ex
Adelgidae (T)		ex
Aphididae (T)	3	4
Cercopidae (T)		ex
Delphacidae (T)		1
Psyllidae (T)		ex
Hymenoptera		
Unidentified Family (T)	3	7
Formicidae (T)	3	6
Tenthredinidae (T)		4
Lepidoptera		
Unidentified Family (T)	3	6
Geometridae (T)	2	
Megaloptera		
Corydalidae (A)	1	
Sialidae (T)		35
Neuroptera		
Unidentified Family (T)	1	
Sisyridae (T)	2	
Odonata - Anisoptera		
Aeshnidae (A)	1	3
Cordulegasteridae (T)		1
Gomphidae (A)	2	
Libellulidae (T and A)	1	1

Table 4.3. Concluded.

Macroinvertebrates	Killman	Unnamed
Odonata - Zygoptera		
Coenagrionidae (A)	24	53
Lestidae (A)		3
Plecoptera		
Leuctridae (T)	1	3
Psocoptera		
Psocidae (T)	1	
Trichoptera		
Unidentified Family (T and A)	1	9
Hydroptilidae (T)	18	15
Leptoceridae (T and A)	21	1
Limnephilidae (T and A)	ex	2
Phryganeidae (A)		1
Polycentropodidae (T and A)	12	40
Sericostomatidae (T)	1	
PELECYPODA		
Sphaeridae (A)	1	
Arachnida		
Unidentified (T)	34	124
Tadpole (A)		13
Fish (A)	4	1

---

[a] Aquatic forms identified.
[b] Terrestrial forms identified.
[c] Exuvia only.

DISCUSSION

Invertebrate abundance and biomass were greater in both acidic ponds but the differences were significant only between Killman and Unnamed Ponds. This pattern is reflected in the structure of the invertebrate fauna too. Faunal distributions typical of acidic ponds (e.g. high populations of Hemiptera and low populations of Ephemeraptera) were more pronounced in the Killman and Unnamed Pond study area.

In 1983 benthic invertebrate sampling and sweep net sampling were both undertaken at Mud and Salmon Pond. Comparing the most relevant benthos data, those from 0.5 m deep samples, to the sweep net data indicates that neither method revealed a significant difference in invertebrate numbers between the ponds. Both methods indicated a trend of greater numbers in Mud Pond. Biomass differences were not significant either, but Mud Pond had more biomass in the sweep net samples and Salmon Pond had more in the benthic samples. Both methods revealed similar differences in the taxonomic structure of the two ponds. It must be emphasized that the two methods sampled very different microhabitats and that neither method is likely to provide a truly accurate representation of what the ducklings were sampling.

5. FISH

INTRODUCTION

Because of their close proximity, yet differing chemical characteristics, an excellent opportunity was presented to study biota in the two pairs of lakes: Mud-Salmon and Killman-Unnamed. An examination of fish populations can reflect the direct impacts of acidification and the indirect effects of such acidification on fishes through alteration of the numbers and diversity of macroinvertebrates.

The qualitative comparisons between fish populations in the circumneutral and acidic ponds are simple: Salmon Pond (pH = 6.8) contains fish, Mud Pond (pH = 4.7) does not; Killman Pond (pH = 6.2) contains fish, Unnamed Pond (pH = 4.8) does not. Fishes survive, grow, and reproduce in Killman and Salmon ponds (the latter supplemented by stocking), while extensive sampling has failed to collect fish in Mud or Unnamed ponds (except soon after a stocking experiment in Mud Pond). The specific objectives of the fisheries work were to (1) identify the fish species present in the ponds, (2) estimate the population sizes or relative numbers of fishes in each pond, (3) identify natural food habits of fishes in the circumneutral ponds, and (4) identify the food habits of fishes artificially stocked into an acidific pond. The intent was to determine the extent of competition between fishes and black ducks as competitors in ponds of markedly different acidity.

METHODS

In 1983, detailed fish surveys were conducted only in Salmon Pond. Brook trout (Salvelinus fontinalis) were collected by angling, and population size estimated using the Leslie depletion method (Ricker 1975) based on regression of catch per unit effort against cumulative catch. On four dates between 30 June and 14 July 1983, 16.5 total hours of effort were expended. Lengths and weights of captured trout were recorded, and stomach contents were preserved in 10% formalin for later examination in the laboratory. As an additional check, 10 man-hours of angling were also attempted in Mud Pond to confirm the absence of fishes in that acidic pond.

Large golden shiners (Notemigonus crysoleucas) ($\geq$ 70 mm TL) in Salmon Pond were sampled with standard minnow traps. Eight baited traps were fished for 2.5 to 3 hr on four dates (11, 13, 14, and 20 July 1983); effort totaled 88 trap hours. Trap sets (< 8m from shore and at 0.5 to 2.0 m depth) were randomly placed around the shore. In addition, 17 golden shiners were collected with gas-powered backpack electrofishing gear; a portion of these fish were preserved with formalin for later measurements. All other trap-caught golden shiners were anesthetized with MS-222, marked by clipping the tip of the upper caudal lobe, and released (minus mortalities) randomly around the pond shore.

The number of large golden shiners in Salmon Pond was estimated using the Schumacher-Eshmeyer multiple census method (Ricker 1975). A Schnabel estimate (Ricker 1975) was also calculated for comparison. Trap data for 13 and 14 July were combined into a single sample point to minimize the effect of suspected "trap shyness" on 14 July of fish marked the previous day. Mortalities of golden shiners from sampling and marking over the study period were added directly to population estimates.

In 1984, fish studies were conducted in Salmon Pond for additional fish diet comparisons, and Killman Pond for fish population studies. Gill nets were also placed in mud and Unnamed ponds to confirm the reported absence of fishes in those acid pond.

Food habits of trout in Salmon Pond were evaluated near the beginning and near the end of the observation period for ducks. Fish samples were collected using "experimental" gill nets and the stomachs of fishes collected were injected with formalin to preserve stomach contents. Samples were returned to the laboratory for analysis.

Two gill nets were set on 29 May, 1984 in both Salmon and Mud ponds, and fished for 1.5 hours in Salmon and 4 hours in Mud. The purpose was to sample fish dietary preferences in Salmon Pond and to confirm the reported absence of fishes in Mud Pond. In Mud Pond, one net was left overnight and repulled the following day, 30 May. Both nets were reset in Mud Pond at different locations, checked periodically during the day, and repulled the following day, 31 May. Nets were again set in Salmon and Mud ponds on 7 June and fished overnight.

Sampling was also conducted in 1984 at Unnamed Pond and Killman Pond. A gill net was placed in Unnamed Pond on 30 June, and was left overnight. Three trapnets and six minnow traps were placed in Killman Pond all day, 18 June, and were also fished overnight, 26-27 June. White suckers and golden shiners were marked by fin clipping on 26 June and sampled the following day in an attempt to make population estimates.

RESULTS

Salmon and Mud Ponds - 1983

Thirteen brook trout were captured by angling in Salmon Pond. Lengths averaged 29.1 cm and ranged from 24.3 to 33.5 cm. Weights averaged 243 g and ranged from 115 to 354 g. Though shallow areas were also fished, trout were primarily caught in deeper areas (> 6 m) of Salmon Pond. The narrow size range of fish caught suggests that all trout were from a single stocking of fish in the previous year. Population size was estimated to be 15 brook trout (95% confidence interval 13-20). These estimates may, however, be conservative. No fish were captured by angling in Mud Pond.

Stomachs of brook trout in Salmon Pond conta largely aquatic insect larvae (69% of the stomachs) and fish (54%), with 38% of the trout stomachs containing rainbow smelt (Osmerus mordax) and 31% containing golden shiners (Table 5.1).

Table 5.1. Stomach contents of 13 brook trout (Salvelinus fontinalis) taken by angling in Salmon Pond, 30 June to 13 July 1983.

Item	Percentage of Stomachs
Aquatic insect larvae	69
Odonata	38
Chironomidae	15
Unidentified insect larvae/nymphs	38
Chironomidae	15
Fishes	54
Rainbow smelt	38
Golden shiner	31

Golden shiners were taken in Salmon Pond in sufficient numbers to derive meaningful population estimates. Of the 664 golden shiners captured, 91 were recaptures (14%). Eleven percent of the fish caught died from handling, marking, or anesthetizing. Schumacher-Eshmeyer and Schnabel estimates were quite close (1,098 and 1,133, respectively), though 95% confidence ranges varied (997-1,224 and 808-1,990, respectively). The true population level may be higher, because of a sampling/marking bias toward larger fishes.

Golden shiners captured in traps and measured (n = 217) averaged 8.8 cm, while those captured by electrofishing in shore areas (n = 21) were smaller, averaging 5.2 cm. An additional sample taken by electrofishing on 11 July, however, averaged 10.0 cm, including a large number of ripe adults.

Salmon and Mud Ponds - 1984

Brook trout were collected to identify food habits in Salmon Pond at the beginning and end of the time ducklings were on the pond. Fifteen trout, ranging in length from 17.5 to 42.9 cm, and in weight from 60 to 960 g, were recovered at the beginning of the period of observing behavior of ducks. Another nine trout were collected on June 7 and nine trout were collected on June 8 (range: 21.3 to 28.2 cm and 93 to 240 g). Stomach samples were partly decomposed, hence the statistical weight of the remaining food items is reduced. However, food items identified did parallel those food items consumed by brook trout in 1983. The absence of fish in Mud Pond was confirmed by 125.5 net hours of sampling.

Unnamed and Killman Ponds - 1984

No fish were caught in gill nets in the acidic Unnamed Pond. Surveys published by the Maine DIFW also confirm the absence of fish.

Over 860 fish (5 species) were captured in Killman Pond (Table 5.2). As there were no recaptures, no valid population estimates could be made. It is estimated that several hundred white suckers (at least 500) are in the pond, competing with other animals for benthic organisms. The number of brook trout in the pond is unknown, but the population probably does not exceed 200. Forage fish species are extremely abundant, though fish were not part of the diet from trout stomachs analyzed in Killman Pond (Table 5.3).

A comparison of the pooled stomach analyses of brook trout in Salmon Pond in 1983 and 1984 (N = 44) with brook trout in Killman Pond (N = 12) indicates a more diverse electivity of trout in Salmon Pond (Table 5.4). This may be partially due to variations in available zooplankton and macroinvertebrates or a larger sample size from Salmon Pond. However, fishes, Odonata, Trichoptera, and Hymenoptera were apparently of greater significance in the diet of fishes from Salmon Pond.

DISCUSSION

The data confirm the presence of numerous fish in the two circumneutral ponds and the absence of fish in the two acidic ponds. Given the large numbers of fishes present in the circumneutral ponds and the absence of fishes in the nearby acidic ponds, it seems likely that the absence of fishes (notwithstanding changes in the zooplankton or macroinvertebrate communities) has an impact on aquatic foods available to or used by waterfowl.

Table 5.2. Summary of number of fishes collected in Mud and Salmon ponds in 1983 and Killman and Unnamed ponds in 1984[a].

Species	Pond Salmon[b] (pH = 6.8)	Mud (pH = 4.7)	Killman (pH = 6.2)	Unnamed (pH = 4.8)
Brook trout	13	0	20	0
Golden shiner	664	0	255	0
White sucker[c]	0	0	102	0
Blacknosed dace[d]	0	0	478	0
Killifish[e]	0	0	12	0

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[a] Salmon and Mud ponds were stocked in 1984, so catches were not reflective of natural levels, and are not used for comparison.

[b] Rainbow smelt were present but were not collected.

[c] *Catostomus commersoni*

[d] *Rhinichthys atratulus*

[e] *Fundulus diaphanus*

Table 5.3. Stomach contents of 12 brook trout taken from gill nets in Killman Pond, 18 to 27 June 1984.

Item	Mean number/fish
Ephemeroptera	0.33
Odonata	0.33
Coleoptera	0.16
Diptera	3.58
Trichoptera	0.08
Araenae	0.08

Table 5.4. Comparison of the mean number of food items consumed by brook trout in Salmon Pond (1983 and 1984 diet analyses pooled) and Killman Pond (1984).

Item	Mean number/fish Salmon Pond	 Killman Pond
Ephemeroptera	0.45	0.33
Odonata	5.72	0.33
Lepidoptera	0.02	0
Coleoptera	1.66	0.16
Dipterea	6.36	3.58
Hemiptera	0.23	0
Megaloptera	0.80	0
Trichoptera	3.18	0.08
Hymenoptera	3.93	0
Pelecypoda	0.09	0
Araenae	0.15	0.08
Fish	0.11	0
N	44	12

6. WATERFOWL

INTRODUCTION

Little is known about the effects of acidification on birds that use aquatic habitats and feed on aquatic organisms (Haines and Hunter 1982). Some anecdotal reports indicate that piscivorous birds are less abundant on acidic lakes (Almer et al. 1978) and one study suggests that eggshell thinning occurs because of aluminum toxicity (Nyholm 1981, Nyholm and Myhrberg 1977). Conversely, it has been suggested that the loss of fish from acidic lakes may favor waterfowl species that use invertebrates for food because competition for food is reduced (Eriksson 1979, Pehrsson 1979, 1984).

In this section we focus on testing two alternative hypotheses:

1. Acidic precipitation can be deleterious to waterfowl because their food--populations of aquatic invertebrates and macrophytes--is reduced.

2. Acidic precipitation can be beneficial to waterfowl because it reduces fish populations that compete with waterfowl for food.

We chose to work on the black duck, *Anas rubripes*, because there has been great concern over long-term declines in its population (Spencer 1981), and because its breeding range coincides with an area of North America that is relatively vulnerable to the effects of acid precipitation (Haines and Hunter 1982).

METHODS

Black duck ducklings were imprinted to humans during the first 8-24 h after hatching, individually marked with tags, and assigned to a brood to give broods equivalent arrays of duckling weights. The day after hatching, broods were weighed at dawn and released to forage on an assigned pond (8 on Salmon and 8 on Mud Pond in 1983, 8 on Killman and 8 on Unnamed Pond in 1984). Use of imprinted ducklings enabled observers to closely monitor duckling behavior with minimal disturbance. Each duckling was watched for 5 min and its activities recorded at 30 s intervals, then another duckling was watched in a rotating sequence. The distance moved by a duckling during 15 s was also recorded. At dusk, ducklings quit feeding and we removed them from the ponds, weighed them, measured their tarsi, and placed them in an overnight box with water and a heating pad. The diet analysis was conducted at the order level because ca. half the samples were too macerated to make accurate counts at a finer taxonomic level. Ducklings were also collected for esophageal analysis of their diets, primarily at the end of each experiment. Duckling techniques are described in detail by Hunter et al. (1985, in press). Because the ducklings were affected by weather and seasonal patterns of invertebrate abundance it is not possible to compare between years and thus the data from the two study areas cannot be compared directly.

RESULTS

Ducklings on the acidic ponds gained weight and increased tarsi length faster than ducklings on the circumneutral ponds (Figs. 6.1, 6.2, and 6.3). Differences in behavior also implied that the acidic ponds had more duckling food. In both study areas the ducklings on the acidic ponds spent less time searching and moving and more time feeding and resting than the ducklings on the circumneutral ponds (Table 6.1). Furthermore, the mean velocity of ducklings was greater on the circumneutral ponds (Salmon = 11.2 m/min, Killman = 13.2) than on the acidic ponds (Mud = 7.6, Unnamed = 6.4)

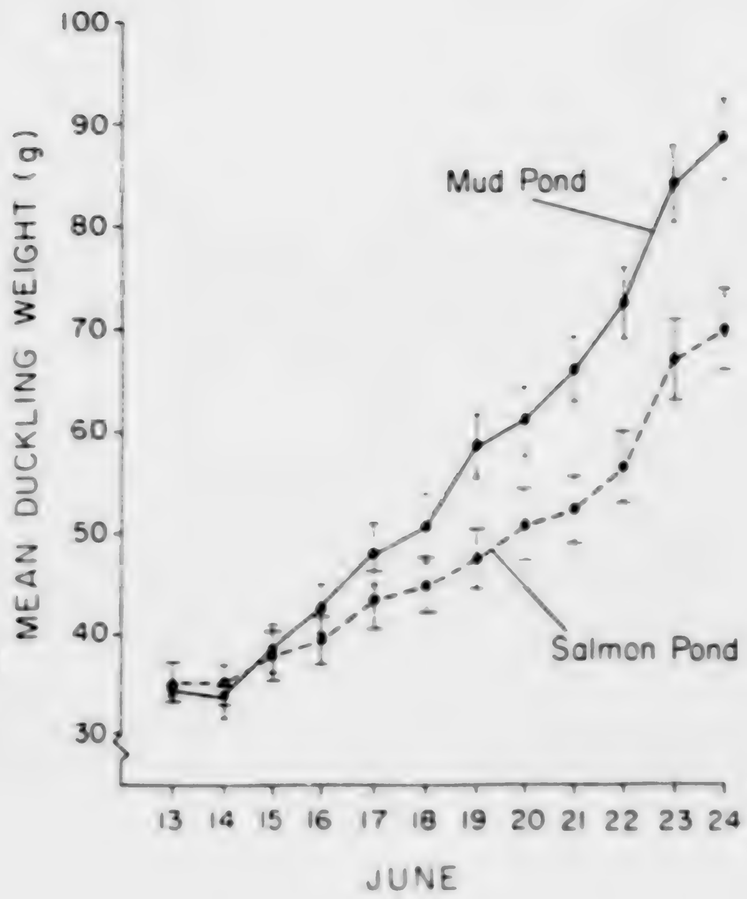

Figure 6.1. Mean weight gains of ducklings on Mud and Salmon ponds (N=16). Slopes were compared using t^2 values ($P < 0.01$). Vertical bars are +/- one standard error.

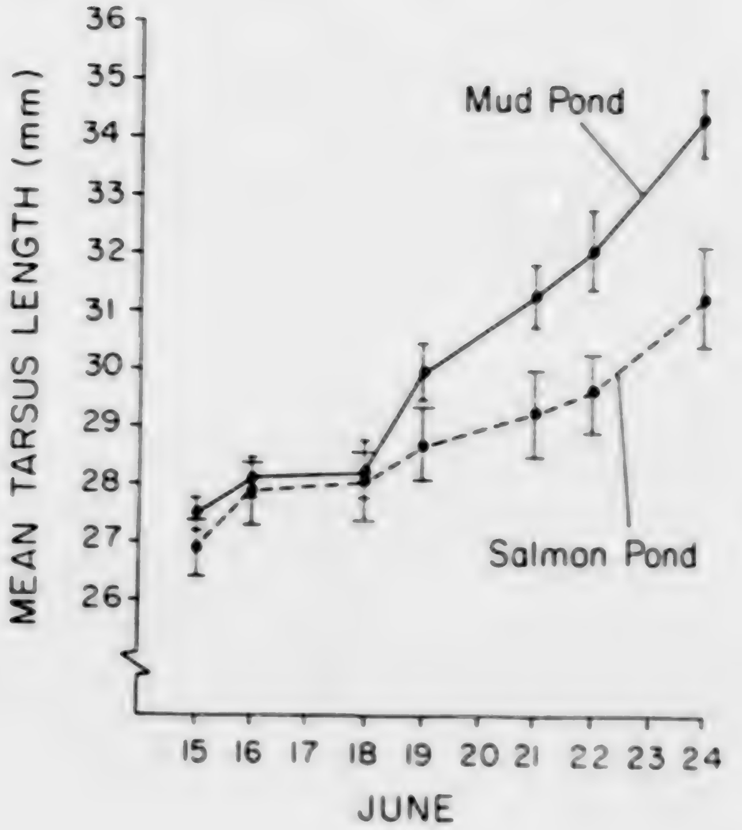

Figure 6.2. Mean tarsus growth of ducklings on Mud and Salmon ponds (N=16). Slopes were compared using t^2 values ($P < 0.01$). Vertical bars are +/- one standard error.

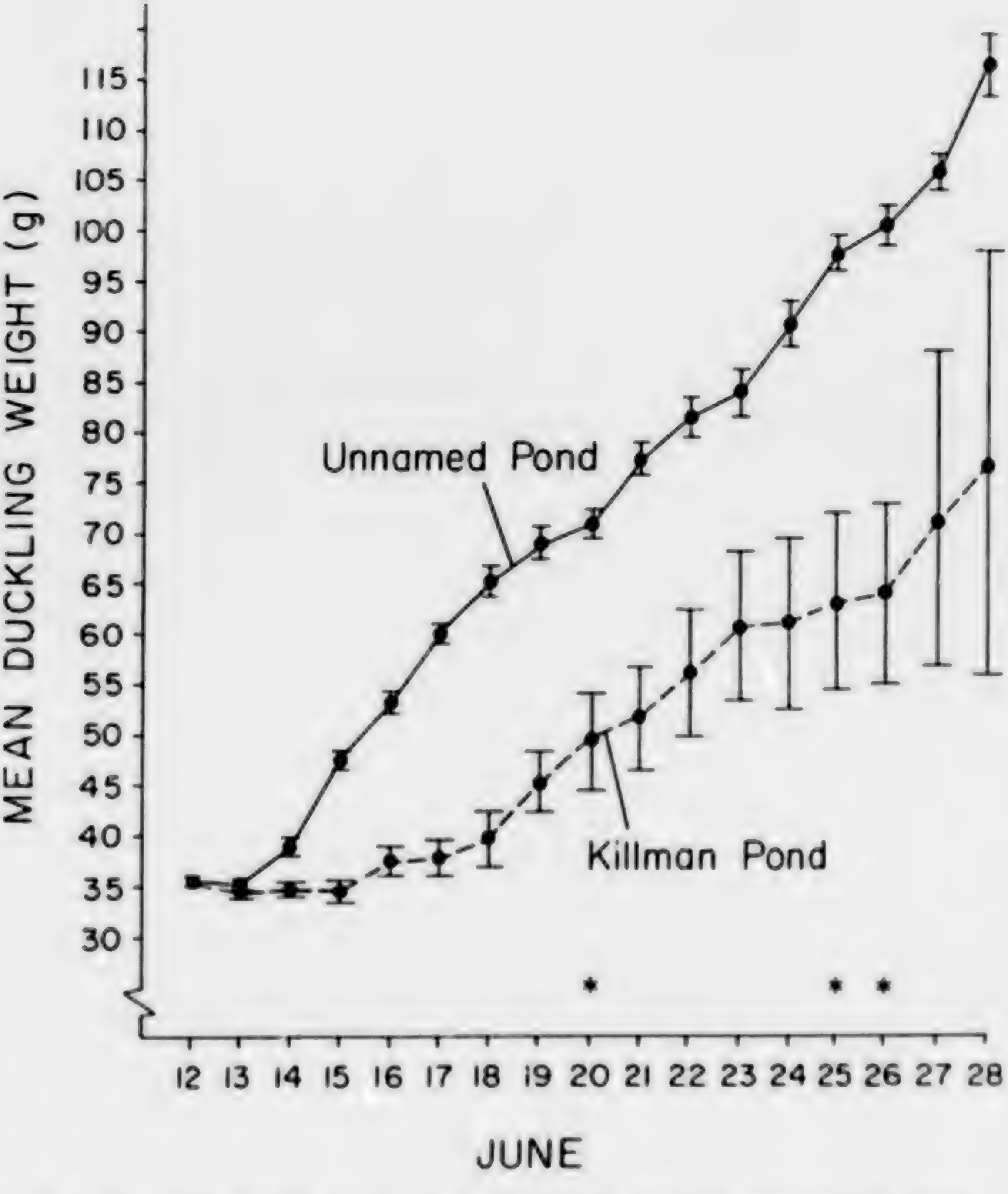

Figure 6.3. Mean weight gains of ducklings on Unnamed and Killman ponds (N=16). Slopes were compared using t^2 values ($P < 0.01$). Vertical bars are +/- one standard error.

* One duckling died at each asterisk on Killman Pond.

(ANOVA, $p < 0.05$), suggesting that ducklings on acidic ponds found food more readily and were able to practice area-restricted foraging.

Table 6.1. Differences between ponds in proportion of time (%) ducklings spent in feeding, searching/moving, rest/comfort and miscellaneous activities.

Behavior	Salmon (pH 6.3)	Mud (pH 4.5)	Killman (pH 6.2)	Unnamed (pH 4.8)
Feeding	19.3	*[1] 22.0	17.4	* 21.6
Search/move	57.8	* 52.1	73.5	* 64.6
Rest/ comfort	19.4	* 22.5	9.0	* 13.7
Miscellaneous	3.5	3.4	0.8	0.1
Number of observations	9,799	10,880	4,077	5,252

Differences were tested using a t^2 value on data derived from a 2 × 2 contingency table (Pond A × Pond B and Behavior C × Not Behavior C) and transformed with an arcsine square root function * $P \leq 0.0005$.

Diets

Diets of the fish and ducklings showed considerable variability (Table 6.2). We compared diets of ducklings and trout using three different indices (Table 6.3). Within each study area, Morisita's index (Horn 1966), and a dissimilarity index (Sneath and Sokal 1973) indicated that diets of ducklings living on circumneutral ponds were more similar to diets of trout from the same pond than they were to diets of ducklings living on acidic ponds. Schoener's index (Wallace 1981) indicated diets of ducklings and trout from all ponds overlapped substantially and to a similar degree

(Table 6.3). The diets of ducklings living in different ponds are not strictly comparable because food availability was different, but we have made these comparisons to emphasize the similarity of fish and duck diets.

Table 6.2. Abundance of invertebrates in the diets of fish and ducklings. (Mean number/ individual fish or duck)

Taxa	Salmon Trout	Salmon Ducks	Mud Ducks	Killman Trout	Killman Ducks	Unnamed Ducks
Nematomorpha			0.20			
Hirundinea		0.25				
Amphipoda		1.08				
Collembola			0.60			1.17
Ephemeroptera	0.45	4.67		0.33	2.5	
Plecoptera			0.20			0.5
Odonata	5.72	3.50	3.00	0.33	1.5	12.33
Lepidoptera	0.02	0.08				
Coleoptera	1.66	0.92	2.80	0.16	1.0	3.17
Diptera	6.36	5.67	62.20	3.58	1.5	11.83
Hemiptera	0.23	4.08	1.80		1.0	2.67
Homoptera		0.08				
Megaloptera	0.80	0.17	0.80			
Trichoptera	3.18	1.17	0.80	0.08		29.83
Hymenoptera	3.93	0.42	1.00			
Pelecypoda	0.09	0.75				
Araenae	0.15		1.20	0.08		0.83
Fish	0.11					
No. of Samples	44	12	5	12	2	6

Table 6.3. Dissimilarity and similarity indices for diets of ducklings and fish.

Indices	Mud and Salmon Ducks	Salmon Ducks and Trout	Unnamed and Killman Ducks	Killman Ducks and Trout
Dissimilarity Index[a]	13.80	1.94	11.21	1.32
Morisita's Index[b]	0.50	0.70	0.38	0.50
Schoener's Index[b]	0.94	0.95	0.95	0.94

[a] Lower values indicate more similarity
[b] 0 = no diet similarity, 1 = identical diets

7. INTERACTIONS

AQUATIC MACROPHYTES

Macrophytes are important components of aquatic ecosystems because they provide food for herbivorous and detritivorous invertebrates, a few fish species, and many waterfowl species (Martin and Uhler 1939). They also provide cover in which invertebrates, fish, and waterfowl can conceal themselves from their respective predators (Moyle 1961, Krull 1970, Ringleman 1980). Thus macrophytes could potentially play a significant role in the results described here by making energetic contributions to certain components of the system. By providing escape or concealment cover macrophytes could also influence predator-prey interactions.

For example, even though young black ducks eat very little plant matter (Reinecke 1979), macrophytes could affect them by either: 1) providing food and substrates to support a greater abundance of invertebrates or 2) providing cover in which invertebrates could hide from predators. However, in our northern study area the circumneutral pond had relatively little vegetation, and in our southern site the circumneutral pond had much more vegetation; we can therefore assume neither of these effects were predominately responsible for the fact that ducklings grew relatively slowly in the circumneutral ponds. By the same token the pattern of macrophyte abundance cannot explain other observed differences between the acidic and circumneutral ponds. The greater macrophyte species richness of Salmon Pond could contribute to its greater diversity of invertebrates, relative to Mud Pond, but this is unlikely to be a major factor.

ZOOPLANKTON AND MACROINVERTEBRATES

Zooplankton community structure in the acidic Mud pond and the circumneutral Salmon Pond appear to be determined by the water chemistry and biotic communities of the ponds. Three large crustaceans, *Diaphanosoma brachyurum*, *Polyphemus pediculus*, and *Acroperus harpae*, were more abundant in Mud Pond. Three crustaceans, *Diaptomus minutus*, *Mesocyclops edax*, *Bosmina* sp., and seven rotifers, were more abundant in Salmon Pond. Salmon Pond had a moderate density of the zooplanktivorous golden shiners (*Notemigonus crysoleucras*).

Research by Brooks and Dodson (1965) showed fish predation can greatly alter zooplankton community structure; fish can cause extinctions of larger zooplankton species thereby favoring smaller zooplankters. This should be especially important to small zooplankter (sp. *Bosmuina*, *Rotiferas*) which are predated on by some large zooplankters (Kerfoot 1977). Rotifers can also be at a competitive disadvantage with some crustaceans (Neill 1984). Mud Pond had a high density of the planktivorous insect *Buenoa* sp.. *Buenoa confusa* has exhibited selective predation amongst Daphnid species (Cooper and Smith 1982), but because backswimmers are mainly littoral and zooplankton mainly pelagic *Buenoa* sp. probably does not influence zooplankton community structure to the extent fish predation can.

Calcium, pH, and total phosphorus were higher in Salmon Pond and the aluminum concentration was higher in Mud Pond. Low pH has been reported to cause toxic effects on crustacean zooplankters, but the data available is mainly for the genus *Daphnia* (Davis and Ozburn 1969, Pots and Fryer 1979, Parents and Cheetham 1980, Havas and Hutchinson 1982). The epilimetic total phosphorus levels in Mud Pond classify it as ultraoligotrophic while

Salmon Pond is oligotrophic. Research by Pejler (1983) indicates zooplankton species richness is highest in moderately oligotrophic to moderately eutrophic lakes and lowest in ultraoligotrophic and hypertrophic lakes. *Buenoa* sp. can prey heavily on zooplankton, but data collected from five acid fishless lakes, in which these backswimmers are common, indicates *Buenoa* sp. does not exclude zooplankton prey. Predation by fish in circumneutral ponds and by the larger backswimmer *Notonecta* sp. in acid fishless lakes seem to limit *Buenoa* sp. numbers (Brett 1985). Cyprinid minnows may have a stronger size-selective impact on zooplankton community structure than do *Buenoa* sp., and under very high densities can virtually eliminate crustacean zooplankters (Brett 1985). The abundance of large bodies crustacean zooplankters may influence the survival and growth of planktivorous fish.

MACROINVERTEBRATES AND FISH

Studies on the impact of foraging fish on invertebrates have been reviewed by Healey (1984). Two approaches were recorded: 1) the invertebrate community was studied with reference to natural variation in abundance of fishes, or 2) the abundance of fish predators or their access to the invertebrate community was manipulated artificially.

Mesh enclosures which either confined a known number of fish to a given area, or excluded fish from a given area were among the methods used. Many of the studies produced results which were inconclusive due to inadequate sampling methods, lack of replication, or failure to define the influence on factors in the ecosystem other than fish. However, results of these studies support the general conclusion that changes in fish abundance are related to changes in benthos abundance and also to changing the composition of the benthos (Ball and Hayne 1952, Macan 1965).

In order to test the hypothesis that the presence of foraging fish reduces the abundance of benthic invertebrates and conversely, the absence of fish increases the availability of invertebrates to alternate predators, ducklings, we excluded fish from areas of Salmon Pond by means of fish exclusion cages and sampled the invertebrates inside and outside the cages at the end of experiment. Similar procedures were carried out in fishless Mud Pond in order to assess the influence of the cage on benthos distribution (cage effects).

We have interpreted our results to mean that the presence of foraging fish in Salmon Pond results in a decrease in the abundance of benthos and an altered benthic community. This suggests that the absence of fish from Mud Pond results in a greater abundance of benthos, especially chironomids, which are available as prey for ducklings. The fact that chironomids are numerically the most important item in the diet of ducklings feeding on Mud Pond supports this finding.

FISH AND WATERFOWL

In both study areas, the ducklings grew faster on the acidic pond than on the circumneutral pond, thus supporting our hypothesis that acidification may be beneficial to waterfowl by extirpating fish competitors. The behavioral data strengthen this conclusion; broods on acidic ponds spent less time moving about in search of food and more time resting, and thus probably used less energy. It is reasonable to assume that differences in the ducklings' growth and behavior were primarily due to differences in the availability of those invertebrates that the ducklings used for food (Hunter et al. 1984). Moreover, the fish exclosure data indicate that the presence or absence of fish was likely to be an important factor in shaping the invertebrate community. Support of the fish-duckling competition hypothesis is further strengthened by the diet data. There was substantial overlap in the diets of trout and ducks; two of the three indices indicated that ducklings sharing a pond with fish had diets more similar to those of the fish than to the diets of ducklings on other, fishless ponds. In short, we believe that the fish and ducklings were competitors because: 1) they exhibited resource-use overlap and, 2) ducklings in the circumneutral ponds experienced resource limitation. Previous reports (Eadie and Keast 1982, Eriksson 1979, 1983, Pehrsson 1974, 1984) have examined the relative distribution of fish and waterfowl and concluded that competition was occurring, but only Eadie and Keast documented diet overlap. We believe our study is the first to document both resource overlap and limitation.

The data presented here pertain to the growth and behavior of newly hatched black ducks on oligotrophic, headwater ponds. To what extent can these data be used to predict the effects of acidification on waterfowl populations in general?

There are two considerations that argue for broader implications. First, it is likely that a duckling's growth and behavior affect its potential survival (Brown and Hunter, in press.). A duckling's growth rate probably influences its chances of survival because larger ducklings are likely to have a better chance of surviving stresses such as inclement weather and migration. Ducklings that spend relatively more time resting and less time moving are probably less vulnerable to predation, a major cause of duckling mortality. Second, ducklings and egg-laying females of most species primarily rely on invertebrate foods (Sugden 1973, Swanson and Meyer 1973) and many species live in habitats where they may compete with fish.

Conversely, there are two considerations that indicate that our results should not be broadly interpreted to suggest that acidification is beneficial to waterfowl. First, in many species, older ducklings switch from a diet dominated by invertebrates to a diet of plants, or in a few cases fish (i.e., mergansers). The effect of acidification on the availability of these foods may be more important than effects of competition for invertebrates. Finally, relatively few waterfowl in northeastern North America live in the types of aquatic ecosystems that are most vulnerable to acidification. Marshes and other eutrophic systems are more important as waterfowl habitat than oligotrophic, headwater lakes. In a study of waterfowl use of wetlands in eastern Maine, Longcore and Stromborg (Patuxent Wildlife Research Lab, Laurel, MD; unpub. data) determined that only 9% of the broods were raised on headwater lakes. Oligotrophic wetlands are quite important to waterfowl in northern Europe (Eriksson, University of Goteborg, Goteborg, Sweden; pers. comm).

We conclude that under certain circumstances the negative effects of acidification on fish populations may be beneficial to ducklings because competition for invertebrate food is reduced.

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16. Abstract (Limit: 200 words)

This study addresses the influence of low pH waters on community structure and species interactions on two pairs of oligotrophic, headwater ponds that were physically similar but with markedly different acidities. The circumneutral ponds had fish and the acidic ponds were fishless. The results showed macrophyte species was lower in the acidic ponds possibly due to low pH. Density of backswimmers was greater on the acidic ponds. Tests indicated that the large numbers of backswimmers present on the acidic ponds replaced fish as a significant planktivore. Although macroinvertebrate species differed between acidic and circumneutral ponds, Diptera were the most abundant macroinvertebrates on both sets of ponds. Diptera were the principle item in the diet of brook trout in the circumneutral ponds. Because of the absence of fish in the acidic ponds, this study suggests that a potential competitor of ducks for aquatic foods had been eliminated. Ducklings on the acidic ponds grew faster, spent less time searching, and more time feeding and resting than ducklings on the circumneutral ponds. There was substantial overlap in the diet of trout and ducks, supporting the hypothesis that ducklings and fish compete for invertebrates and that, under certain circumstances, the negative effect of acidification on fish may produce a beneficial effect for ducklings.

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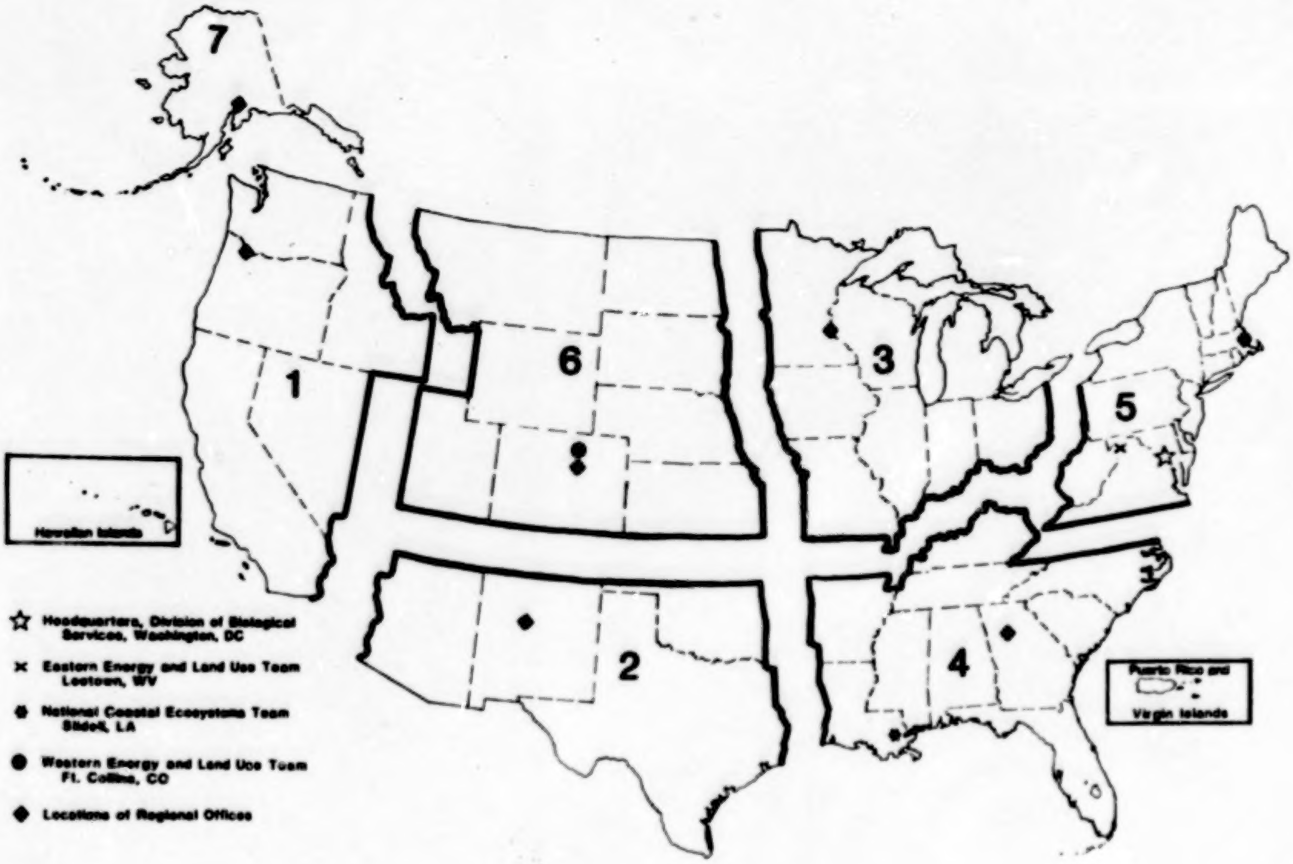
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